HF RADIO SYSTEM NETWORKING

Phase-I Report
"Preliminary Concepts and Recommendations"

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J. P. Basart, Co-Investigator

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March 3, 1986

College of
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Prepared by

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March 3, 1986

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PREFACE
to the
Phase-I Report

The Phase-I report covers work performed in January and February of 1986. It is the first phase of a study of networking capabilities and network design issues for the HF Testbed System. It is anticipated that the work will be performed in several phases. However, this report applies only to the Phase-1 tasks described in the proposal and repeated below.

The complete study is associated with an Independent Research & Development project at RCA Corp. concerning Adaptive HF Communications Techniques. It will be a sub-task of the RCA Networking Implementation Study. This study is meant to provide an analysis of present HF Testbed System neworking capability and a recommendation for expansion of the present signal format, frequency-hopping pattern selection, and link quality analysis software to allow for multiple uses within a tactical environment. As a part of this requirement, an adaptable networking organization that can overcome and report on dynamic HF channel conditions, during hopping, will be described. RCA personelintend to use this information for proposing hardware, software, and system modifications to the HF Testbed System to allow interoperability in order to perform networking performance evaluation tests. They also intend to demonstrate rudimentary network links using multiple HF Testbed Systems.

The following subtasks were identified for Phase-1 of this work:

1) Analyze the current HF Testbed System capabilities, describe them in terms of the standard ISO reference model and read literature on networking provided by RCA.

2) Analyze and describe the protocol for adaptive features, possibly at the link layer, that will be required for use in a network environment.

3) Define additional functional elements that will be required in the HF Testbed System in order to demonstrate a minimal network implementation. Propose three network topologies that could be used in demonstrations of the augmented system.

The development of a detailed design description for adaptive features has proved to be too large a task for the time allotted to the Phase-I effort. However, the issues and concepts have been described so a detailed design description can be started in the next phase. We have attempted to provide as much background material in the form of network descriptions and literature references as seems practical. Major issues such as routing protocol and relay protocol have been studied but final conclusions have not been reached due to the complicated nature of these requirements. We have attempted to provide design direction, or at least enumeration of the alternatives, for all issues. Much of the project time has been used trying to understand the problem and reading applicable literature. Now that the learning curve has been traversed, the project time in the next phase will be spent more on implementation descriptions.

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PART 1.

System Overview

1.1 Introduction

This report documents the Phase-I effort of a multiphase project to develop a practical concept for an HF Radio Network. In Phase-1, the major goal was to examine the networking problems peculiar to HF radio and begin the design description for a network concept that can be implemented with the RCA Frequency Agile Communication System. It is our intent to provide as much information as possible about the preliminary thinking that has been done. The project hours budgeted for Phase-I are not sufficient to permit detailed design descriptions of the network implementation so we have chosen to document the general concepts that were identified during the project period. Also, we describe the HF Radio Network in terms of the ISO/OSI model.

The report is organized into seven parts as indicated by the Table of Contents. Part 1 is the system overview, Part 2 is the formal ISO/OSI model description, Part 3 is the network design description. Included in other parts are the references, acronym and term definitions, and a quick topic summary.

The following is the working definition we have followed in our study of the HF Radio Network:

> "A group of radio terminals (or "nodes") that have the ability to communicate using the same signalling waveform and to relay messages using established protocol.
>
> Some of the nodes (called network control nodes) have executive functions for keeping the message flow orderly. The network also has the ability to establish predetermined circuits (directed routing) between two nodes prior to the actual message passing."

We have assumed that the network may have very poor physical connectivity and therefore a robust scheme of message relay must be employed. The signalling structure has be modeled after the one presently in use by the FACS testbed system.

1.2 General Description

The HF Radio Network requirements and characteristics have been compared to those encountered in Computer Local Area Networks (LAN) and the national phone system. HF networks can be described in the terminology

of the ISO/OSI model but the description is far from perfect. The layer definitions used in the ISO/OSI model provide a good framework for describing the conceptual design of the network but they cannot be translated one-for-one into an actual hardware/software design. Some of the functional concepts needed to describe an HF network do not fit precisely into a single layer. In addition, such issues as network management are not clearly addressed with the model. However, the model will be applied as strictly as possible in this report.

The networking concept that will be described is most similiar to the national telephone system used in the U.S. This prototype was chosen because it will lead to a reliable implementation for an HF network. The telephone network and an HF Radio Network however, differ in the following aspects:

1. The HF network is inherently a broadcast network which means that each node in a local group can hear the traffic of all the others. In contrast, the phone network allows only the two nodes involved in traffic passing to hear the traffic. The broadcast characteristic allows an "all-call" feature so that all nodes in the local group may receive the same message simultaneously. This operational characteristic is somewhat similiar to party line or conference calling in the phone system.

2. The HF network concept will support both random and directed routing of messages. The phone system requires that the message path or route be established prior to the actual passing of traffic and will not allow dynamic changes in the routing once established. In contrast, a broadcast system will support random routing of message units. Thus, every network node can act as a switching or relay "office".

3. The HF network has variable degrees of connectivity and its connectivity relationships are inherently different from those used in the phone system. Although the phone system routing must contend with defective or busy circuit paths, the degree of connectivity makes it a simple matter to establish alternate paths. The concept of connectivity is much more complex for a frequency hopping HF network because the quality of the link between two nodes may be different for every hop frequency. Thus, the degree to which linking is established among all the nodes is a complicated variable. When the HF network has a low degree of connectivity (i.e. many nodes not linked and more linked only over a narrow hopping bandwidth) it is much difficult to establish a directed route than is the case for the phone system. Because connectivity is so variable, a practical HF Network concept should permit both random routing and directed routing. Random routing would be used when directed routing has a lot of problems.

4. Because (in a broadcast network) it is possible to have a direct path between two nodes, the HF network will allow the establishment of temporary detached networks for the purpose of handling large volumes of traffic or to implement special operational requirements. The detached network would have its own unique AJ

channel and Sync channel but would still remain loosely connected to the parent local groups by a special permission protocol. This detached net may also be formed with nodes from different local groups. Link establishment would be accomplished with assistance from the network control stations along the tree structure path between the local groups. It would require the passing of security keys to the affected nodes.

Several problems arise in the frequency-hopping HF radio network that are not as severe in other commonly used networks. For example, the frequency hopping required for this network adds an additional level of complication to the design of the physical and link layers. The need to achieve frequency hop synchronization makes the process of obtaining access to the network more complicated than typical systems currently in use such as in satellites and amateur packet radio. The narrow bandwidths employed in HF also impose severe restrictions on the design because the synchronization and network management overhead consume a significant portion of the channel capacity. The packet design, data interleaving, frame interval, node addressing and similiar issues must all be carefully traded off to obtain the best network thruput.

1.3 Network Operation

This section contains general comments about network operation. The topics have not been arranged in any particular order.

To implement the planned netork concept and protocols, the Network Control Cluster for the local group must have the security keys and current Sync Channel for any other local groups or higher level networks that they have to communicate with.

To implement a priority interrupt capability, the local group must maintain information about the absolute propagation delay between any two nodes. This can be incorporated as one of the parameters in the connectivity matrix. The need arises because the packet time allowed for interrupt frames is much smaller than the uncompensated propagation delay uncertainty. If priority interrupt is unavailable, the disconnected node can still access the net in the normal way but must then use the CSMA protocol just like any other node.

At the end of each packet are some frames dedicated to the interrupt function where the transmitting node listens for a possible interrupt. This is a type of reverse link synchronization so the node trying to interrupt can synchronize interrupt transmissions with the receiver timing of the remote node. To do this requires a knowledge of the absolute time delay.

At the present time, no way has be thought of to put every node in the network on a universal time so all transmissions can be synchronous. The design that is proposed has all nodes keeping a local version of the time-of-week and a table of propagation delay offsets (when available). The network does not depend on having all the delays specified but can offer enhanced capability such as "real time" interrupt priority if the delays are available.

A scheme has been designed that will permit all nodes to develop the delay table by passing pseudotime delay around to all network nodes. This requires a special network operation where all nodes transmit to all other nodes that have connectivity. This scheme is described elsewhere in the report.

Packet lengths should remain in the range one-half to four seconds because of frame and chip length restrictions as well as ACK/NAK overhead. The network will usually operate with ACK/NAK protocol.

The link layer and the physical layer functions may be performed in part or in entirety by the modem device of the present FACS design. The ISO/OSI description is only a conceptual description and should not be used as a constraint on the organization of hardware and software functions in the modem. EDAC is conceptually located in the link layer. Multipath correction is also a part of the link/physical layer combination. The ISO/OSI Model is used only for concept and not for physical implementation.

Multiple data rates are accomodated by selecting the signalling mode that will support the selected data rate. The mode selected and the corresponding data rate are related one-for-one. It is forseeable that only the maximum rate is restricted and lower rates allowed for in the DTE interface. This could be one of the menu selections when the radio terminal is initially configured. Each stage of information handling in the model should incorporate data buffering so that each layer as well as external devices can operate either synchronously or asynchronously. In other words, the implementation provides an interface that appears to be synchronous. The data rates would be chosen so that the network could support them by buffering. Under normal operational scenarios, all that is needed is to provide the DTE with electrical signalling at the proper data rate. The DTE interface must be properly buffered and timed so the DTE thinks it is synchronous.

Synchronous transmission may be able to be supported when the messages are being passed between two nodes that have connectivity at all hop frequencies but this would be a special mode of operation and these favorable conditions may not exist frequently enough to make it practical. The current design thinking is to avoid this mode of operation and use buffering and somewhat less link efficiency to present a synchronous full-rate inteface to the DTE.

DTE synchronism is handled at each radio terminal and is made transparent to the network. It is totally reconstructed at the destination end. Baud rate, word length, parity, stop bits, xon, xoff, and other such issues are dealt with locally in each radio terminal at the application and presentation layers.

The scenario of how communication is actually accomplished is not completely specified at this time (17 Feb 1985). Some general comments can be given now. All nodes in the local network must have the same security key and the same Sync (or acquisition) Channel. This permits completion of the first stage of acquisition which is to synchronize to the Sync Channel and decode the time-of-week and AJ Channel in current use. The AJ Channel is acquired and then the node may access the network using CSMA. This does

not provide access to another local group because of a lack of the proper security keys. These keys are needed because the AJ Channel is determined, in part, using the keys. Communication must be established with another local group through a specified protocol with the Network Control Cluster because the cluster has knowledge of the necessary keys.

CSK is used in the encoding schemes and may be embedded in some synchronization frames. The modem will be capable of sending CSK codes and the EDAC should take advantage of this. This has not been well thought out or specified yet.

Packet overhead to deal with hop synchronization, packet preamble, and packet addressing and control is quite large. A typical efficiency from the input to the link layer to the transmitted chips is sixty percent. The overhead for hop synchronization is quite heavy but is required to allow synchronization within one packet time interval.

The radio terminal constantly monitors the AJ Channel and decodes all messages. The higher layers, however, do not respond to messages unless the proper node address is recognized. The radio terminal gathers LQA and delay information constantly. A radio terminal must establish hop sync everytime it decodes the transmissions of a different (or new) node. This is necessary because of the time delay variability to every node. It can only be avoided if sufficient network traffic is dedicated to determining absolute time delays. As the design is presently envisioned, each node keeps a table of the pseudotime delay of the received packets from every node heard and, in that way, can listen for a particular node's transmissions or scan the node/delay table to see if there is any network traffic at all from the nodes that can be heard. The present sync scheme works without any knowledge of network time.

The Sync Channel also derives its suite of frequencies and random sequence, in part, from the security keys.

Further study needs to be made of the nature of the messages that will be sent. Distribution of lengths, priority, and other information could allow us to make a better decision on packet length and overhead tradeoff.

Constraints of the present FACS System that may have an impact on network and signal structure design are:

1. The time required for the R/T to transition from transmit to receive and visa versa is about 20 milliseconds.

2. For LPI, we may have to deal with variable power levels and may want to establish the circuit with the minimum of power.

Dynamic frequency allocation is not presently being proposed. It is felt that the network management overhead required would be too much for the low chipping rates inherent in HF. It could be implemented as a special mode when a detached network is formed using only two nodes because then the nodes could transfer the LQA information as a normal course of their handshaking. For a local group with a large number of nodes, the network

would have to guarantee that each node received the latest connectivity matrix information from all other nodes and this is a large overhead. However, LQA information is still very necessary to help the Network Control Cluster make the decision to change to a better AJ Channel.

The AJ Channel designates both the suite of frequencies that will be used in the hopping sequence and the pseudorandom frequency command sequence. As a preliminary decision, we have concluded that 256 predefined suites of hopping frequencies will provide for AJ Channel selection that permits compensation for propagation effects and peacetime frequency allocations. During times of conflict, this ceases to be an issue.

The current design will not be constrained by the requirements of dynamic frequency allocation. In the next phase, the baseline could be analyzed to determine the level of capability for this function. This will require a tradeoff study of network performance as the design is modified in various ways to accomodate dynamic frequency allocation.

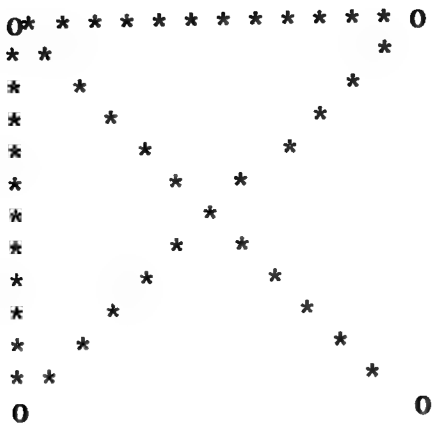
1.4 Topology

The topology for an actual network can be described at both the "logical" level and the "physical" level. A radio network (by virtue of its broadcast nature) has a physical topology that can be modeled as a completely (or fully) connected network (Tannenbaum, p. 9). At any instant in time, however, an HF radio network is irregularly connected because all of the nodes do not have a usable link between them. To illustrate these definitions, various connections are shown below.

The 4-node radio network illustrated below (where each node is represented by O and connections by *) is physically fully connected.

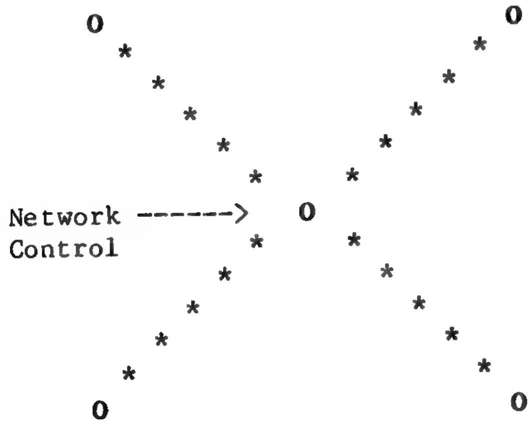
```
O* * * * * * * * * * * * O
* *                    * *
*   *                *   *
*     *            *     *
*       *        *       *
*         *    *         *
*           *            *
*         *    *         *
*       *        *       *
*     *            *     *
*   *                *   *
* *                    * *
O* * * * * * * * * * * * O
```

If this is an HF radio network, some of the nodes may not have a radio link between them and the physical connection may become irregular as shown below:

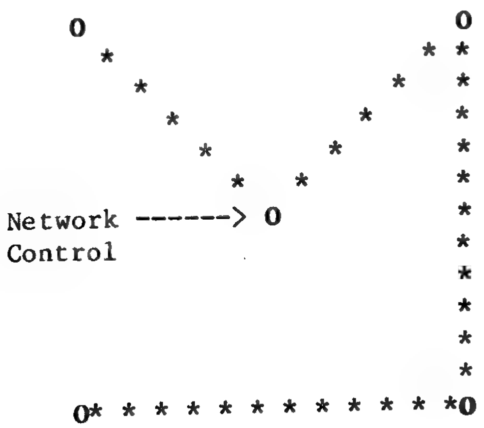


So we see that, with irregular physical connectivity, some of the nodes must relay messages so that every node may send messages to every other node.

Now we show the same four nodes logically connected in a star configuration so that a fifth node can act as network control:



Although it is assumed that every node has good connectivity with the network control node, this may not always be the case. When this occurs, the HF radio network must take advantage of all the physical connectivity available. An example of poor connectivity and the need for message relay is represented by the physical connectivity show in the diagram below:



The logical network topology chosen for this report is the star-connected network. The entire network is organized into a hierarchy of star-connected networks. The hierarchy is organized as a tree structure and each higher level will be referred to as a tier. The diagram below is a very simple representation of part of the total tree structure that would be implemented. It would, in reality, have higher tiers than shown and more local groups.

```
        :-----------------------------------------------------------:
Tier-5  :                            LG-1                           :
        :--------------------------------------:--------------------:
Tier-4  :                LG-1                  :        LG-2        :
        :--------------------:-----------------:--------------------:
Tier-3  :        LG-1        :      LG-2       :        LG-3        :
        :------:------:------:------:------:------:------:------:
Tier-2  : LG-1 : LG-2 : LG-3 : LG-1 : LG-2 : LG-1 : LG-2 : LG-3 :
        :------:------:------:------:------:------:------:------:
Tier-1  :  #   :  #   :  #   :  #   :  #   :  #   :  #      #   :
        :------:------:------:------:------:------:------:------:
```

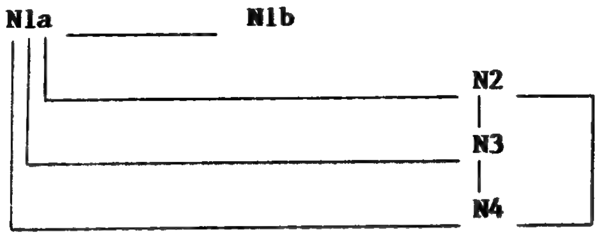
The #-sign represents all the nodes under the local group.
LG = Local Group

The network control cluster is the center of the star. The lowest level network will be called the local group. The network will not always operate in a star protocol, however, because the broadcast nature will permit direct connection between some of the nodes. This will allow any node in the local group to transmit a group message by encoding the message address in a way that disables selective calling and enables "all-call" operation. Broadcasting also permits traffic directly between two nodes thus eliminating the need for relaying by the network control cluster. The network control cluster will coordinate this activity.

A local network group is connected in a manner similar to the end office (local exchange) and local loops used by the phone system. The main difference is that two nodes of the local group can exchange messages without relay through net control. However, net control may require that the nodes obtain permission by requesting a token. Net control may also grant permission to the two nodes to form a detached subnet and pass messages on a separate AJ channel. Because we must deal with a broadcast system, the local group could also be considered to be connected as a "party line".

An alternate scheme for local network connectivity would be to assign each node to a different AJ channel and access to that channel would be available only through network control. This approach seems unnecessarily restrictive because the messages passed within the local group are generally of common interest. In other words, the necessity to maintain privacy for all node members is not a key design constraint. In those cases where privacy is needed, a detached subnet could be used. The main purpose of the subnet is to keep the designated AJ channel of the local group free of long messages and available for calling. It is anticipated that the majority of messages will be "all-call" and intended for everyone in the local group.

To illustrate the connectivity of a simple local group, a local group with five nodes is shown in the figure below. The two nodes in the Network Control Cluster, N1a and N1b, are connected by double lines and the three "regular" group nodes, N2, N3, and N4, are connected by single lines.

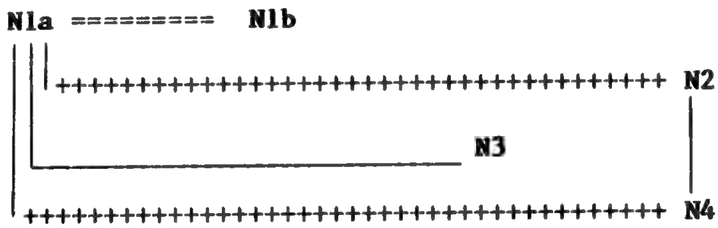


The connectivity matrix for this local group would be:

$$\begin{bmatrix} C1a1a & C1a2 & C1a3 & C1a4 & C1a1b \\ C21a & C22 & C23 & C24 & C21b \\ C31a & C32 & C33 & C34 & C31b \\ C41a & C42 & C43 & C44 & C41b \\ C21a & C22 & C23 & C24 & C21b \\ C1b1a & C1b2 & C1b3 & C1b4 & C1b1b \end{bmatrix}$$

and we see that it is fully connected.

A local group with a two-node detached subgroup is represented by the figure below:



The connectivity matrix for this local group would be:

$$\begin{bmatrix} C1a1a & ++++ & C1a3 & ++++ & C1a1b \\ ++++ & C22 & --- & C24 & C21b \\ C31a & --- & C33 & --- & C31b \\ ++++ & C42 & --- & C44 & C41b \\ C1b1a & C1b2 & C1b3 & C1b4 & C1b1b \end{bmatrix}$$

The network control cluster still has the necessary connectivity information to communicate with the detached network formed by N2 and N4 (+ signs in matrix) but does not monitor the traffic. When the detached network is ready to rejoin the Local Group, they can do so without resynchronization unless the local group has changed AJ channels. When this happens, they have to go through a normal acquisition sequence.

The nodes in the network control cluster have an established succession order, e.g. N1a, N1b, N1c etc. When one of the nodes becomes inoperative, the cluster will initiate a new node into the group at the bottom of the succession order. It is assumed that the nodes in the network control cluster have a very high degree of connectivity. The cluster has a pre-established number of nodes that does not vary. Each node in the cluster knows its position in the succession order. The "second in command" will assume control if communication with the top node in the cluster cannot be established.

It is assumed for this initial design that the connectivity of the local group may be low but does not dynamically change over the time interval needed to transmit a message. If the circuit is lost during message transfer, the circuit must be re-established and the rest of the message sent. We are proposing that the destination node will be able to tell the source node what packets have and have not been received because of the message and packet identifications that are sent. If the network is using random routing, the problem of dynamically changing connectivity is automatically accounted for. If the network is operating with a very volatile connectivity then random routing should be used for these periods. When there is a need for high-volume point-to-point traffic, the necessary relay stations in the detached network must have good connectivity and directed routing. Then if circuits are still lost, the network could still use the technique of circuit re-establishment. We are also assuming that in most cases, all nodes in the local group will have direct communication with one of the nodes in the Network Control Cluster.

If one of the nodes in the local group does not have direct connectivity with the Network Control Cluster, it can call any node it hears and establish that node as a relay station. To contact the available node to establish a relay, the disconnected node can either select it from the local connectivity matrix, listen for a station currently active and call it, or request help by broadcasting in the "all-call" mode, an option which is available to it at all times. This can be done dynamically as long as the connectivity changes occur on a time scale less than the length of ten to twenty packets. The node addressing is structured in a manner similiar to a military command structure. The "all-call" feature would take advantage of this to require every node to listen to group messages.

To implement the planned netork concept and protocols, the Network Control Cluster for the local group must have the security keys and current Sync Channel for any other local groups or higher level networks that they have to communicate with.

A suitable scheme is also needed to communication outside the local group. Messages outside the local group must be routed using the directed routine technique. Broadcast and random routing cannot be used because the nodes of separate local groups will not be listening to the same AJ Channel. The network control cluster will be the only nodes that have the security keys necessary for synchronization with other network levels.

The higher level star networks are analogous to the concept of Level 1,2,3,4,5, etc Offices in the phone system. The connectivity will be different in some aspects. For example, it would be possible to have

connections from a net control station in one group directly to a station node in another group. This type of connection must be carefully regulated and permission to establish this type of circuit would have to be granted by both respective network control clusters.

1.5 Network Transaction Description

The radio network will be contrasted with the phone network in this section. The description will be given at both the logical level and physical level. Greater detail is given in Part 3.

1.5.1 Logical Network Transactions

1.5.1.1 Phone Network

Source	Network	Destination
-Look up phone number		
-Place the call	-Establish the circuit	-Answer the call
-Exchange messages	-Maintain the circuit	-Exchange messages
-Terminate the call	-Terminate the circuit	-Hang up

1.5.1.2 Radio Network

(TBD)

1.5.2 Physical Network Transactions

1.5.2.1 Phone Network

(TBD)

1.5.2.2 Radio Network

(TBD)

1.6 Access

Three separate aspects of network access need to be addressed. They are:

1. Initial waveform synchronization.
2. Routine access.
3. Interrupt access.

Initial access to the network (sometimes called "cold start") requires hop, chip, frame, and packet synchronization. The signalling waveform is designed so that a node that has the proper security keys, node addressing, and sync channel number can acquire the designated sync channel and decode

the network time (time-of-week) and AJ Channel in current use. These are then used to acquire the AJ Channel and begin receiving network messages. Initial synchronization can be accomplished after receiving a complete packet transmitted by another node in the local group.

Routine access to the network channel will be requlated using the Carrier Sense Multiple Access (CSMA) technique. This is required because of the broadcast nature of the communication channel. The CSMA algorithm will simply be a listen-with-random-try-and-timout scheme. In reality, the sensing of the "carrier" is actually the detection of the encoded transmission of another network node. This prevents any false alarming from "stray" signals. This is one of the justifications for embedding the sync channel into every packet. A practical scheme for CSMA has not yet been conceived. Preliminary thinking indicates there may be packet collision problems that could make the technique unstable. This should be given considerable thought before an implementation is chosen.

Interrupt access to the network is provided so that a source node with a long message can be selectively interrupted between packets. The packet design accomodates this by requiring the transmitting node to listen for a specific period of time near the end of the packet time slot. Interrupt can only be use by a node that knows the propagation time delay to the transmitting node. A scheme that can be used to determine propagation time delay is described elsewhere in this report. When the actual delay is known, the transmission of the node trying to do the interrupt can be timed to arrive in sync with the receiver of the node that is to be interrupted. In this way, the latter's receiver does not have to go through a synchronization procedure. The capability to do interrupt should be included in any future design concepts although it may not ever be actually used. The network might always operate with ordinary CSMA and let every node compete for channel access after every packet transmission. It would be prudent to include it until future networking tests show that it is not needed.

1.7 Routing

The network will support two types of message or packet routing. They are:

1. Random Routing.
2. Directed Routing.

Flexability in routing design and structures is needed to support all the possible waveforms (described in Part 3.) and network protocols that must be used in an advanced HF frequency hopping design. The need to be able to operate with existing equipment (equipment that may not have automated networking capability) also makes this necessary.

Directed routing is a technique where the circuit path that will be used to pass the message is established prior to actual message transmission. Although this is the scheme used in the telephone system, the circuit paths and routing protocol used in the HF Radio Network would be different because of the relatively low level of connectivity of the network. This routing technique requires ACK/NAK handshaking protocol for

all relay nodes in the circuit. It must be used to establish circuits out of the local group. By comparison with the random routing technique, it makes more efficient use of the network channel capacity but is not as robust because the loss of a node requires that a new circuit be established before the message is completed. In addition to the packet addressing described for random routing, the packet would contain information about the nodes that relayed it so acknowledgement could return on the same circuit.

Random routing is also supported by the HF Radio Network and is possible because of the broadcast characteristics of radio networks. In random routing, the originating node broadcasts packets to every node in the network that can hear it. All of those nodes, in turn, rebroadcasts the packet. This process repeats until the network has been flooded to the point were the packet reaches the proper destination node. Random routing can be used for both initial message transmission and message acknowledgement. To support random routing, each packet must contain a a packet number, possibly an appended relay identifier, and the total number of packets in the message. The destination node can then reassemble the message from the randomly received packets and request retransmission of any garbled or missing packets. A practical implementation of random routing is not easy. For example, a node must be able to stop the rebroadcast cycle. This would require some type of rebroadcast counter and preset upper limit or reception of an acknowledgement from the destination node. Because of the randomness, each packet may arrive by a different circuit and at a different time. For this reason, This technique requires each node to keep a log of messages relayed so that the same packets do not circulate forever. The protocol on how to request retransmission of garbled or missing packets has not been determined. Could a circuit log be used to send acknowledgement back using directed routing? How do the relay stations keep track of packets that are received because of retransmission and not because of circulation? Should a relay station ask for repeats of garbled packets? If so, how will the network survive this potential heavy loading? These questions and others remain to be answered.

To make the network flexably efficient and robust, both types of routing are needed.

The problem of how to request retransmission of garbled or missing packets is far from solved. The design assumption to this point has been to have relay stations request retransmission on a packet-to-packet basis but this might not be practical. One alternate technique would be to require a relay node to collect the entire message before retransmission. This would work quite well for directed routing but, for random routing, it would require every node to send retransmission requests so a complete message can be assembled and this would reduce network thruput. Also it would increase message delay in the channel because the first packets of the message would be delayed in relaying until all packets had been correctly received. A decision on these options will have to wait until more is know about the operational impact of these performance characteristics.

1.8 ISO/OSI Model Overview

1.8.1 Introduction

A detailed presentation of the HF Radio Network in terms of the formal ISO/OSI model is given in Part 2 of this report. This section is intended to present an overview of the model in a simple, and much less rigorous, form. Also, this section will present the basic ideas by contrasting a radio system with the phone system.

The layers referred to in this section will be defined as follows:

Layer 0	Communications Medium
Layer 1	Physical Layer
Layer 2	Data Link Layer (or Link Layer)
Layer 3	Network Layer (or Communication Subnet Layer)
Layer 4	Transport Layer
Layer 5	Session Layer
Layer 6	Presentation Layer
Layer 7	Application Layer
Layer 8	User
-------	Network Management Layer

Layer 0, Layer 8, and the network management layer are not part of the official ISO/OSI model but are defined here because they are needed to more completely describe the concept of HF networking.

The "standard" model can be used as a design guide and in preparing a design concept document but when the network is actually designed, the layer concept may change. Some of the higher layers might be eliminated or be implemented as a null layer and the link and physical layers may be partitioned into sublayers. For this reason, the model illustrated here may differ, in some minor aspects, with the model presented in Part 2 of this report.

The simple "apartment house" diagram below that will be used to represent the model was adapted from the 1986 ARRL Handbook, page 19-46. It shows the source node, destination node, and one relay node. The relationship of the network management layer to the other layers is shown on the next page.

```
    Source Node              Relay Node            Destination Node

:-------------------:                              :-------------------:
: 8. USER           :                              : 8. USER           :
:-------------------:         Protocols            :-------------------:
: 7. APPLICATION    :<---------------------------->: 7. APPLICATION    :
:-------------------:                              :-------------------:
: 6. PRESENTATION   :<---------------------------->: 6. PRESENTATION   :
:-------------------:                              :-------------------:
: 5. SESSION        :<---------------------------->: 5. SESSION        :
:-------------------:    :-------------------:     :-------------------:
: 4. TRANSPORT      :<-->: 4. TRANSPORT      :<-->: 4. TRANSPORT      :
:-------------------:    :-------------------:     :-------------------:
: 3. NETWORK        :<-->: 3. NETWORK        :<-->: 3. NETWORK        :
:-------------------:    :-------------------:     :-------------------:
: 2. LINK           :<-->: 2. LINK           :<-->: 2. LINK           :
:-------------------:    :-------------------:     :-------------------:
: 1. PHYSICAL       :<-->: 1. PHYSICAL       :<-->: 1. PHYSICAL       :
:-------------------:    :-------------------:     :-------------------:
           :               :              :              :
           :               :              :              :
         :-------------------:          :-------------------:
         :  COMMUNICATIONS   :          :  COMMUNICATIONS   :
         :      MEDIUM       :          :      MEDIUM       :
         :-------------------:          :-------------------:
```

Some general comments can be made about the model. For example, the flow of information is vertical from layer-to-layer. The protocols shown between layers represent information removed (or added) that was added (or removed) by the corresponding layer at the other node. The three highers layers (Application, Presentation, Session) are not shown for the relay node because they are not used to relay packets. The communications medium is shown as two separate entities (for clarity), but they are actually the same for HF radio networks (the ionosphere). A Radio Terminal used for relay has all the capability of any other node. The purpose for not showing the higher layers was to clearly illustrate that they are not needed.

The diagram below shows the relationship of the ISO/OSI Layers to the network management layer. Note that network management can interface directly with any ISO/OSI layer and information can be passed between any two layers if done through network management. The network management layer performs services for the other layers. It does not have an interface to the User or the Communications Medium.

```
          ISO/OSI Layers                       Management

      :-------------------: Protocols   :--------------:
      : 7. APPLICATION    :<----------->:              :
      :-------------------:             :              :
      : 6. PRESENTATION   :<----------->:              :
      :-------------------:             :   NETWORK    :
      : 5. SESSION        :<----------->:  MANAGEMENT  :
      :-------------------:             :    LAYER     :
      : 4. TRANSPORT      :<----------->:              :
      :-------------------:             :              :
      : 3. NETWORK        :<----------->:              :
      :-------------------:             :              :
      : 2. LINK           :<----------->:              :
      :-------------------:             :              :
      : 1. PHYSICAL       :<----------->:              :
      :-------------------:             :--------------:
```

1.8.2 Communications Medium

The constraints imposed by the communications medium used for HF radio are the major design drivers in a practical network design.

The communications medium has a major influence on the network design because it can affect connectivity, access, bandwidth, and reliability. The designers of the ISO/OSI model seem to have concentrated on communication media that have both excellent connectivity and bandwidths sufficient to support networking overhead with only a modest reduction in network thruput. Since the medium for HF radio may be line-of-sight, or ground wave, or ionospheric refraction, it clearly does not fall into this category. It is characterized by usable bandwidths of only a few kilohertz and connectivity that can be very poor or non-existant. Also, requirements for frequency hopping (AJ) and adaptive power control (LPI) make design of the physical and link layers much more complicated than encountered with most other systems. Furthermore, the characteristics of the HF radio medium are highly volatile because ionospheric conditions are directly dependent on time-of-day, season, and solar activity. During solar storms ionospheric propagation can be totally lost for minutes or hours (or even days in arctic regions). Even when the ionosphere is "normal", the received radio signal can be severly distorted by multipath and dispersion. All of these contingencies and a corresponding course of action must be part of the networking design.

To appreciate the difficulty imposed by ionospheric propagation, consider the communications media used in other types of networks. Sometimes the medium is wire pairs such as those used for telephones and RS-232 links. These are characterized by excellent connectivity, access, and reliability but have relatively low bandwidths. Coaxial media are excellent in all respects but are relatively expensive. Surface microwave radio links have excellent connectivity and bandwidth, but usually have fixed access and only modest reliability when compared to wires or cable. Satellite microwave links have excellent bandwidth and reliability but are very expensive and have limited access.

The medium for the phone systems can vary from wire pairs to coaxial links, to fiber optic links, to microwave links, to satellite links. It is anticipated that a future HF radio network concept may use relay capability that would include any of these also, but the network design described in this report uses only line-of-sight, or ground wave, or ionospheric refraction as the communications medium.

Another special problem encountered in the design of an effective frequency-hopping HF radio network is the requirement for a wideband antenna system since the medium-to-physical-layer interface is an antenna. For the vehicular application, this creates the need for a frequency-hopping antenna coupler which will impose an upper limit on the hopping rate. This issue has not been treated in this report. It has been assumed that the antenna system can support hopping rates up to 200 hops per second.

1.8.3 Layer Description Summaries

1.8.3.1 Physical Layer

The physical layer and link layer are functionally separate in the ISO/OSI model but their physical implementation is highly integrated. For this reason, the functional descriptions given in the next two sections should not be construed as constraints on the implementation of actual hardware and software.

The physical layer is concerned with the transmission and reception of electrical signals over the communications channel. For binary signalling systems, the basic units of information are call "chips". The physical layer receives a stream of data bits from the link layer and converts them to chips and transmits the chips. There may or may not be a one-to-one correspondence between bits and chips. The physical layer also receives a stream of chips and converts them to a stream of bits to be sent to the link layer. Some of the issues addressed by the physical layer are:

1. Signalling waveform (Modulation type)
2. Signalling rate (and chip width)
3. Carrier frequency
4. "one-zero" ambiguity
5. Transmitter operation
6. Receiver operation
7. Antennas and antenna couplers
8. Simplex/duplex operational mode
9. Electrical fault detection
10. Signal presence detection
11. Frequency synchronization
12. Phase synchronization
13. Chip synchronization
14. Frame synchronization
15. Quality-of-Service (LQA)
16. Frequency hopping
17. Adaptive power management

The physical layer for the HF Radio Network contains the following physical and functional elements:

-"Carrier Sense" (for CSMA)
-Frequency Hopping
-MSK Modulation/Demodulation
-Receiver/Transmitter Hardware and Software
-Antenna Coupler
-Antenna

1.8.3.2 Data Link Layer

The Data Link Layer provides error-free transmission and reception between network nodes. In essence, the link layer provides all the services necessory for network layers of different nodes to exchange error-free bit streams.

The data link layer must process the bit stream received from the physical layer and convert it to an error-free bit stream for the network layer. In other words, the link layer must remove all transmission errors that occur due to noise and fading in the medium and random errors in the modulation/demodulation process.

To accomplish its functions, the link layer organizes and manages the bits in blocks called packets. This processing can be coarsely divided as follows: packet assembly/disassembly, error encoding/decoding, multipath and dispersion correction, data interleaving and data buffering.

During transmission, the link layer processes the bit stream from the network layer. It adds error detection and correction (EDAC) encoding, data interleaving, packet preamble (to indicate packet boundary), packet header information, frame check sequence, and any miscellaneous layer management information needed. The bit stream sent to the physical layer is thus organized into Link Layer Packets.

During receiving, the link layer processes the bit stream from the physical layer. It performs error detection and correction (EDAC) decoding, data de-interleaving, multipath and dispersion correction, packet synchronization (recognition of packet boundaries), packet header decoding, frame check sequence decoding, and removes miscellaneous layer management information.

The link layer must also manage the retransmission of lost or garbled packets and any ACK/NAC protocol. To do this, it must buffer all transmitted packets and decode node address, packet number, and message number information. It must also buffer received packets to the extent that the information they contain can be put into the correct order before being sent to the network layer. This ordering may also be needed prior to de-interleaving. The link layer will also initiate the transmission of any acknowledgement packets.

The protocol followed by the link layer can be standardized for compatibility purposes. For example, one possible standard is the Level 2

Protocol such as CCITT Recommendation X.25 or the AX.25 Amateur Packet-Radio Link-Layer Protocol. This standard has not been studied for this report. It would be analyzed in Phase II.

In some packet systems, the hardware and software entity used to implement the functions or protocols required for the link layer is called the PAD or packet assembler/disassembler. The PAD is really a unit of hardware that has been programmed to implement the standard protocol and interfaces a modem at the physical layer and a computer at the network layer. The PAD is not officially part of the ISO/OSI model and does not fit the model very well but, nevertheless, is a very practical way to implement the packet management functions.

1.8.3.3 Network Layer

The network layer controls how packets travel through the network.

It orders the bit stream received by the transport layer into packets we will call Network Layer Packets. The network layer also provides the authorized class of service and determines the type of routing that will be used. Examples of currently defined protocols for the network layer are CCITT X.25 or X.75.

(TBD)

1.8.3.4 Transport Layer

The transport is responsible for connection establishment and connection release. It also organizes the data received from the session layer into transport layer packets. It does error detection and recovery for its packets. It also manages the various classes of network connection.

(TBD)

1.8.3.5 Session Layer

(TBD)

1.8.3.6 Presentation Layer

The presentation layer manages; the mapping of character sets, data types, security encoding and decoding, code conversion, and data compaction.

(TBD)

1.8.3.7 Application Layer

This layer is the interface between the user and the ISO/OSI modeled network. All windows (or pages) for menu driven input/output are contained

here. It determines all of the parameters of the node configuration, checks passwords, and interfaces all external devices that are addressed by the control packets.

The application layer is where all custom features are implemented for the network such as: special abbreviated commands, short node names, system status monitoring, error notification, self-test, data rates and modulation types etc.

(TBD)

1.8.3.8 User

(TBD)

1.9 Signal and Physical-Layer Packet Structure

This section is intended to give an introduction and overview of the signal structure and associated packet structure for the physical layer. A detailed presentation of the physical-layer packet structure will be given in Part 3 of this report.

The selection of a proper design for a physical-layer packet involves the tradeoff of many performance factors. The following factors have been identified:

1. Ease of hop synchronization.
2. Network thruput.
3. Packet identification overhead.
4. Interleaving length for burst error detection.
5. Priority interrupt.

The packet consists of many hop frames. In turn, each hop frame contains many MSK chips. The message, control, and sychronization bits must all be encoded in this structure. Structure details are given in Part 3 of this report.

The packet length, hop frame length, and chip length must all be traded off in the design. The chip width determines the signal bandwidth. The frame length determines how many chips can be transmitted per hop dwell. The packet length determines both the number of hop frames that can be sent per packet and the minimum transmission interval. A long packet length would reduce network management overhead but would also make the channel less efficient for short messages and ACK/NAK protocol. Likewise, it is possible to make the packet length so short that all the channel thruput is consumed in overhead. Considering the bandwidths and channel overhead needed for HF networks, the most practical packet lengths appear to be in the one-half to four second range. The packet length that has been chosen for illustration in approximately two seconds long.

A variety of signalling waveforms should be incorporated in the design to allow the radio terminal to communicate with a variety of presently

implemented radio systems and in a variety of data rates for secure and unsecure transmissions. Secure transmissions are those using frequency hopping, advanced EDAC, data encription with security keys, and LPI. The following modulation modes and bandwidths have been identified:

1. SSB, 3 kHz
2. AFSK, 3 kHz
3. MSK Unsecure Data, 3 kHz
4. MSK Unsecure Data, 6 kHz
5. MSK Unsecure Data, 12 kHz
6. MSK Secure Data, 3 kHz
7. MSK Secure Data, 6 kHz
8. MSK Secure Data, 12 kHz
9. Digital Unsecure Voice (MSK or FSK)
10. Digital Secure Voice (MSK or FSK)

The HF frequency range must be channelized in 3 kHz channels (or multiples of the lowest RF bandwidth that will be used). If channel separations of less than 3 kHz are used, the hop bandwidths would overlap and destroy the orthogonality needed for frequency hop multiple access. This is a critical design issue that is frequently ignored in the frequency hopping literature. Channel spacings of 100 Hz are definitely not needed and are actually harmful if frequency division multiple access is needed -- as is surely the case for tactical HF communications. "Friendly-jamming", due to non-orthogonality, can be fatal when the spectrum is crowded.

Because of bandwidth considerations, some of the modulation modes may be constrained by regulatory agencies during peacetime. Channel spacing for 6 kHz and 12 kHz modes would be multiples of the spacings used for 3 kHz modulation.

Although channel spacing is several kilohertz, the frequency accuracy of the channel would still be specified in the range 0.5 to 1.0 PPM. This type of accuracy in within the present technology limit of reasonably priced temperature compensated crystal oscillators. This limit translates into a maximum frequency error of 15-30 Hz in the HF frequency range 2-30 MHz. Accuracy of the nominal channel frequency is needed so that frequency and phase tracking can be readily implemented.

Hop dwell time should be in the 5-20 millisecond range. This would produce hopping rates of 50-200 hops-per-second. Faster hopping would result in severe design constrains on the RF portions of the user equipment and would result in fewer chips-per-hop if reasonable RF bandwidths are used.

RF bandwiths wider than those proposed suffer increased signal dispersion and multipath fading problems and are difficult to implement with reasonable compensation algorithms. MSK bandwidth efficiency would be offset by signal distortion and subsequent decoding error problems. Fewer chips-per-hop would also increase the overhead in each hop frame because fewer chips could be used to represent data.

These design implementations are all well within the inherent capability of the FACS Testbed System and should not impose any major design change problems.

HF RADIO SYSTEM NETWORKING

PART 2.

ISO/OSI Model Design Description

This part of the report details the functions of the layers which compose the HF radio network. Each layer is related to the ISO reference model and will be described in detail. The purpose of this description is to provide an abstract system definition which can be used by a system designer to construct a HF networking radio. This model however does not indicate how the radio should be implemented in both hardware and software. A paper on the OSI model is included in this report.

2.1 Layer overview

Figure 2.1 shows the six layers in the HF networking radio and how they correspond to the seven layers of the ISO model. The functions and services provided by each layer will be detailed in Sections 2.2 through 2.8.

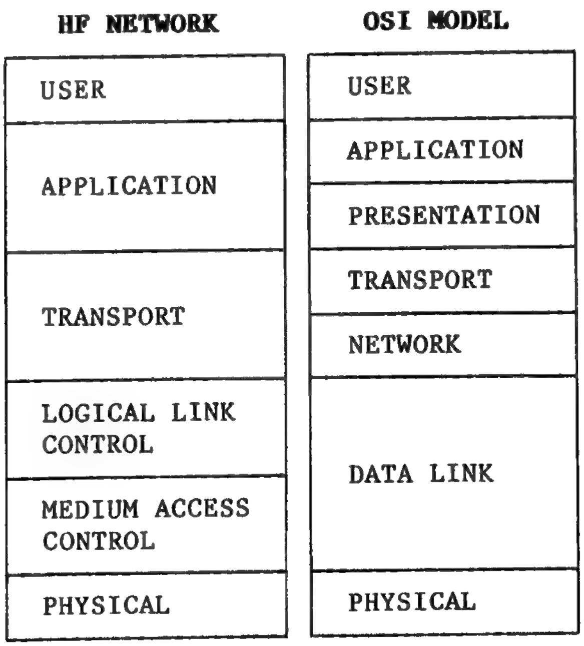


Figure 2.1 HF Radio Model.

The functions of each layers will be briefly described below.

2.1.1 User Layer

The user layer is the program or programs that need to use the network. These entities can consist of a voice system, data system, and a control system. This layer uses the services provided by the application layer to communicate to another radio on the network.

2.1.2 Application Layer

The application layer provides an interface between the user layer and the network. This interface consists of a series of subroutines which the user entity can call. This layer corresponds to the application layer in the OSI model. The presentation layer which follows the application layer in the OSI model is not needed in the radio. Any conversion functions can take place in the application layer since the conversions will be minor. The application layer also provides the interface between the user and any network service function defined by the layers.

2.1.3 Session Layer

The session layer provides the the point to point communication control. This layer is responsible for establishing, managing, and terminating the connections between to application entities. This service is only used in point-to point-connections and not in a message broadcast. This layer corresponds to the session layer in the OSI model.

2.1.4 Transport Layer

The transport layer provides a reliable transparent transfer of data between end points in a point-to-point with acknowledgment connection. This layer handles the acknowledgment of the messages and any retransmissions which are needed. The functions of this layer are primarily used for transmissions that require acknowledgments. This layer corresponds to the transport layer in the OSI model.

2.1.5 Logical Link Control Layer

The logical link control layer provides the relay functions, packet creation, and address recognization. This layer also provides an interface between the transport layer and the details of the actual physical network. This layer corresponds to the upper part of the data link layer. The network layer is not needed in this network.

2.1.6 Medium Access Control Layer

The medium access control layer provides a controlled access to the physical network. This control access is used to avoid any collisions which occur when multiple stations transmit simultaneously. This layer corresponds to the lower part of the data link layer.

2.1.7 Physical Layer

The physical layer provides the transmission of a bit stream over the physical medium. This layer provides all encoding and decoding for the waveform. This layer will provide the AJ and non AJ transmission services. The channel and network synchronization is provided by this layer. This layer corresponds to the physical layer in the OSI model. This layer also corresponds to the present HF radio system.

2.2 User Layer

The user layer is a set of programs and processes which use the HF network. The interface between the User layer and the HF network is via the application layer described in Section 2.3. The user layer supports three types of data, digital voice, digital data, and digital control. This data can be sent to other nodes in the network by using the application layer data service routines. The data can be sent in one of three mode. The first mode is broadcast mode where any station in the broadcast group can receive the data. The next mode is open mode where the data is sent to all stations which can receive the packets. This mode is the "all call" mode which is found in radio networks. The last transmission mode is point-to-point and is used to send data to a specific node in the network. The HF network also provides for acknowledged data transmissions, relayed transmissions, and both types at once.

2.3 Application Layer

The application layer is responsible for provideing the user interface to the network. This layer is also responsible for any data conversions which might be necessary. These data conversions will not be specified in this report but could consist of baud rate conversions and character translations.

2.3.1 Application Layer Functions

The primary function of the application layer is to provide an interface to the network for the user layer. This interface is generally a series of subroutines which the user programs or processes can use.

2.3.2 Application Layer Data Services

The data service routines for the application layer are listed below. There is no need to explain the functions of each service routine individually. The names of the routines are self explanatory. The names consist of three parts, the first part is the transmission type. The types of transmission are broadcast, point-to-point, and open (same as "all call") mode. The next part of the name is a single letter which indicates if the transmission will be relayed (N = no relay, R = relay). The last part is a letter which indicates if the message is to be acknowledged (N = no ack, A = ack). There are services which are used for making and terminating a

call in point-to-point mode. There are also receive services (RCV) which are used to indicate when data has been received from the network. The quantities in parentheses indicate parameters passed to the routine.

```
BROADCAST_R_N(DA, DATA)
BROADCAST_N_N(DA, DATA)
POINT_N_A(DA ,DATA)
POINT_N_N(DA, DATA)
POINT_R_N(DA, DATA)
POINT_R_A(DA, DATA)
OPEN(DATA)

BROADCAST_R_N(DA, VOICE)
BROADCAST_N_N(DA, VOICE)
POINT_N_A(DA ,VOICE)
POINT_N_N(DA, VOICE)
POINT_R_N(DA, VOICE)
POINT_R_A(DA, VOICE)
OPEN(VOICE)

BROADCAST_R_N(DA, CONTROL)
BROADCAST_N_N(DA, CONTROL)
POINT_N_A(DA ,CONTROL)
POINT_N_N(DA, CONTROL)
POINT_R_N(DA, CONTROL)
POINT_R_A(DA, CONTROL)
OPEN(CONTROL)

CALL(DA, DATA)
WAIT_CALL(DA, DATA)
TERMINATE(DA, DATA)

CALL(DA, VOICE)
WAIT_CALL(DA, VOICE)
TERMINATE(DA, VOICE)

CALL(DA, CONTROL)
WAIT_CALL(DA, CONTROL)
TERMINATE(DA, CONTROL)

RCV_CALL(SA, DATA)
RCV_TERM(SA, DATA)

RCV_CALL(SA, VOICE)
RCV_TERM(SA, VOICE)

RCV_CALL(SA, CONTROL)
RCV_TERM(SA, CONTROL)

RCV(SA, DATA)
RCV(SA, VOICE)
RCV(SA, CONTROL)
```

where,

DA = DESTINATION ADDRESS
SA = SOURCE ADDRESS
DATA = USER DIGITAL DATA MESSAGE
VOICE = USER DIGITAL VOICE MESSAGE
CONTROL = USER DIGITAL CONTROL MESSAGE

2.4 Session Layer

The session layer is responsible for providing a user-oriented connection service. The transport protocol is responsible for creating and maintaining a connection between endpoints. The session layer provides a user interface by adding value to the basic connection service.

2.4.1 Session Layer Functions

The session layer has three basic functions. The first function is to provide for session establishment and maintenance. The second function is to provide for dialogue management and the last function is crash recovery.

2.4.2 Session Layer Data Services

There are 11 session layer data services which are provided to the application layer. The first five are concerned with sending data. The first data send routine is SESS_SEND_BROAD and is used to send a broadcast message. The next service is SESS_SEND_POINT and is used to send a point to point message without acknowledgment. The next send service is SESS_SEND_POINT_ACK and is used to send a point to point message with acknowledgment. These first three send services have the same four parameters. The first parameter is the destination address. The second is a relay flag used to indicate if the message should be relayed. The next parameter is the message type. There are three data types which are provided by the HF network. These data types are digital data, digital voice, and digital control. The last parameter is the user data. The fourth send service is SESS_SEND_OPEN and is used to send a message in open mode. This service has only two parameters, the data type and the data. The last send service is SESS_SEND_CONFIRM and used to provide confirmation that the data was sent. The only parameter a status flag.

The next five data service routines are concerned with making and terminating a call. The first of these is SESS_CALL and is used to make a call. The next routine is SESS_TERM and is used to terminate a call. These two routines have the same three parameters. The first parameter is destination address. The next parameter is the relay flag and the final parameter is the message type. The next call establishing routine is SESS_CALL_CONFIRM and is used to confirm the call. The parameter is the status of the call. The next two routines are concerned with receiving a call. The first one is SESS_RCV_CALL and is used to indicate a call has arrived. The next routine is SESS_RCV_TERM and is used to indicate when a call termination has arrived. These two routines have the same two

parameters. The first is the source address of the packet and the second is the connection type.

The last data service routine is SESS_RCV_DATA and is used to indicate when data has been received from the network. This routine has three parameters. The parameter is the source address of the data. The next parameter is the data type and the last parameter is the data. The session layer data service routines are listed below:

```
SESS_SEND_BROAD(DA, RELAY, TYPE, DATA)
SESS_SEND_POINT(DA, RELAY, TYPE, DATA)
SESS_SEND_POINT_ACK(DA, RELAY, TYPE, DATA)
SESS_SEND_OPEN(TYPE, DATA)

SESS_SEND_CONFIRM(STATUS)
SESS_CALL(DA, TYPE)
SESS_TERM(DA, TYPE)
SESS_CALL_CONFIRM(STATUS)
SESS_RCV_CALL(SA, TYPE)
SESS_RCV_TERM(SA, TYPE)
SESS_RCV_DATA(SA, TYPE, DATA)
```

where,

```
DA      = DESTINATION ADDRESS
SA      = SOURCE ADDRESS
TYPE    = DATA TYPE FLAG
RELAY   = RELAY FLAG
STATUS  = BOOLEAN VALUE
```

2.5 Transport Layer

The transport layer is responsible for the error free transmission of data between to stations when the station is sending messages that require acknowledgment. This layer is also responsible for adding the station address to the data.

2.5.1 Transport Layer Functions

There are three basic functions of the transport layer. The first function is to add the station address to the data packet. The second function is to send the acknowledgment for packets received correctly and that required an acknowledgment. The last function is to retransmit any message for which an acknowledgment was not received with in a certain timeout period. This function is only used for messages that require acknowledgment.

2.5.2 Transport Layer Data Services

There are ten data service functions provided by the transport layer. The first four service routines are used for data transmission. The first

one is TRANS_SEND_BROAD which is used to send a message in broadcast mode. The second service is TRANS_SEND_POINT which is used to send a point point to point message. The third service is TRANS_SEND_POINT_ACK which is used to send a point to point message with acknowledgment. The last data send service is TRANS_SEND_OPEN which is used to send the message in open mode. These three routines all have the same four parameters. The first parameter is the destination address. The next parameter is a relay flag that is used to indicate if the message should be relayed. The next parameter is the data type. The last parameter is the user data. This routine has two parameters. The first parameter is the message type and has values of DATA, VOICE, and CONTROL. The second parameter is the data message.

The next four routines are used to establish and terminate calls for point to point connections. The first two routines are TRANS_CALL and TRANS_TERM and are used to make a call and terminate a call. These routines have the destination address and a relay flag as parameters. The next two routines are TRANS_RCV_CALL and TRANS_RCV_TERM and are used to indicate when an incoming call has arrived or when a call has been terminated.

The next data service routine is TRANS_SEND_CONFIRM and is used to indicate when the message has been sent. This routine returns the status as its only parameter. The last data service routine is TRANS_RCV and is used to receive data. This routine has three parameters. The first parameter is the source address of the message. The next parameter is the message type and the last parameter is the ser data. The transport data service routines are listed below:

```
TRANS_SEND_BROAD(DA, RELAY, TYPE, DATA)
TRANS_SEND_POINT(DA, RELAY, TYPE, DATA)
TRANS_SEND_POINT_ACK(DA, RELAY, TYPE, DATA)
TRANS_SEND_OPEN(TYPE, DATA)
TRANS_CALL(DA, TYPE)
TRANS_TERM(DA, TYPE)
TRANS_RCV_CALL(SA)
TRANS_RCV_TERM(SA)
TRANS_CONFIRM(STATUS)

TRANS_RCV(SA, TYPE, DATA)

where,

DA     = DESTINATION ADDRESS
SA     = SOURCE ADDRESS
TYPE   = MESSAGE TYPE (VOICE, DATA, CONTROL)
STATUS= BOOLEAN VARIABLE
RELAY = MESSAGE SENT IN RELAY MODE
```

2.5.3 Transport Layer Network Services

There are three network services provided by the transport layer. The first service is SET_ACK_MODE and is used to set the acknowledgment mode for the messages. There are two acknowledgment modes which are used. The first is ACK with relay and the other is ACK without relay. The only parameter is

the acknowledgment mode. The next two services are used to set and read the source address of the station. The two services are SET_SA and READ_SA and both have just the source address as a parameter. The network services are listed below:

SET_ACK_MODE(MODE)
READ_SA(SA)
SET_SA(SA)

2.5.4 Transport Layer Implemetation

This section can be used to provide a guideline for implemetation of the transport layer protocol. This guideline is not a complete description of the transport protocol internals but is an overview of some of the important issues.

2.5.4.1 Retransmission Strategy

There are two reasons why data must be retransmitted in the HF network. The first reason is that a data unit arrives to the physical layer but is discarded because of an incorrect frame check code. In this case the transport layer does not receive the packet. The other case is the packet fails to reach the station. To cover both these cases a positive acknowledgment (ACK) must be used. In the case where the message is broadcast the sender will assume that most station heard the message and will not require an ACK. The user can also specify that a point-to-point message may not use ACK. For efficency we do not require one ACK per packet. Rather, a cumulative acknowledgment can be used, where an ACK is used to acknowledge all packets up to the sequence number sent with the ACK. Thus the receiver may receive packets numbered 1, 2, and 3, but only send back an ACK 3. The sender must interpret ACK 3 to mean that number 3 and all previous data units have been successfully received.

If a data unit does not arrive sucessfully, no ACK will be issued and a retransmission is in order. To cope with this situation, there must be a timer associated with each data unit as it is sent. If the timer expires before the data unit is acknowledged, the sender must retransmit.

The value of the timer should be set to just greater than twice the propagation delay. If the timer is too small there will be too many retransmissions and if the timer is too large the protocol will be too sluggish.

If a data unit is lost and then retransmitted, no confusion will result. If however, an ACK is lost, one or more data units will be retransmitted, and, if they arrive successfully, will be duplicates of the previously received data units. Thus the sender must be able to recognize duplicates. The sequence numbers help, but, nevertheless, duplicate detection and handling is no easy thing. The duplication of data units is only a problem if relaying is involved, otherwise only one message can be in transit. But, with relaying multiple packets can be waiting at relay stations.

There are two cases:

A duplicate is received prior to the call termination
A duplicate is received after the call termination.

In the first case, two tactics are needed to cope with a duplicate received prior to a close of connection:

The receiver must assume that its acknowledgment was lost and therefore must acknowledge the duplicate. Consequently, the sender must not get confused if it receives multiple ACKs to the same data unit.

The sequence number space must be long enough so as not to "cycle" in less than the maximum possible data lifetime.

The second problem of duplicates after the close can be cured if a connection to the station is not permitted until after the duplicates have been flushed from the network.

2.5.4.2 Call Setup

The connection is established using a three way handshaking. In three way handshaking the sender transmits a request for call with a sequence number. The receiver sends back a request for call with his sequence number along with an ACK with the sender sequence number. The sender then transmits an ACK with the receivers sequence number.

2.5.4.3 Call Termination

The call termination is handled in the following manner. Each close has the sequence number plus one of the last data units sent. And the ACK contains the sequence number received in the close.

2.6 Logical Link Control Layer

The Logical Link Control Layer (LLC) is responsible for the packet creation and address recognization. This layer is also responsible for relaying any packets. The acknowledgment packets are created and recognized at this layer.

2.6.1 LLC Layer Functions

The major function of the LLC layer is to assemble the packets to be sent to the MAC layer. The station address is recognized at this layer. If the address matches the data is sent to the transport layer. If the address does not match the data is ignored. This layer will also provide the relay service if the station has been designated as a relay station. The generation of the acknowledgment packet is done when the transport layer requests an acknowledgment. When a acknowledgement is received the LLC layer informs the transport layer.

2.6.2 LLC Data Services

The LLC layer provides six data service routines to the transport layer. The three routines deal with data transmission. The first is LLC_SEND_BROAD which is used to send a broadcast message. The next send routine is LLC_SEND_POINT which is used to send a point to point message. The last send routine is LLC_SEND_OPEN and is used to send an open broadcast message to all stations on the same AJ channel.

There is one data receive routine called LLC_RCV. This routine has five parameters. The first parameter is the source address of the message. The second parameter is the type of message which was received. The types of messages are Voice, Data, and Control. The next two parameters are the packet and message sequence numbers which are used by the transport layer. The last parameter is the data.

The last two data service routines are LLC_SEND_ACK and LLC_RCV_ACK and are used to send and receive acknowledgments. Both routines have five parameters. The first two are the source and destination addresses. The next parameter is relay and is used to determine if the acknowledgment should be relayed. The last two parameters are the packet number and the message number which are used by the transport layer for error control.

The data services are listed below:

```
LLC_SEND_BROAD(DA, RELAY, TYPE, PN, MN, DATA)
LLC_SEND_POINT(DA, RELAY, ACK, TYPE, PN, MN, DATA)
LLC_SEND_OPEN(TYPE, DATA)
LLC_RCV(SA, TYPE, PN, MN, DATA)
LLC_SEND_ACK(DA, SA, RELAY, PN, MN)
LLC_RCV_ACK(DA, SA, RELAY, PN, MN)
```

where,

DA = DESTINATION ADDRESS
SA = SOURCE ADDRESS
RELAY = INDICATES MESSAGE TO BE RELAYED
ACK = INDICATES MESSAGE TO BE ACKNOWLEDGED
PN = PACKET NUMBER
MN = MESSAGE NUMBER
TYPE = MESSAGE TYPE
DATA = MESSAGE

2.6.3 LLC Network Services

There are two network services provided by the LLC layer. The first service is SET_RELAY_MODE and is used to set the station up as a relay station in one of three relay modes. The first relay mode is flooding where all stations relay all messages that are received. The second relay method is random relaying where a random set of station relay the messages. The last mode is the designated relay mode where a station is set up as a relay station.

The other network service is SET_LINK_SA and is used to set the source address of the station for address recognization. The network services are listed below:

SET_RELAY_MODE(MODE)
SET_LINK_SA(SA)

2.7 Medium Access Control Layer

The medium access control layer (MAC) is responsible for the ordered access to the network. This ordered access is done by using a Carrier Sense Multiple Access (CSMA) method.

2.7.1 MAC Layer Functions

There are two basic functions of the MAC layer. The first function is to provide entry in the network. The second function is to provide an ordered access to the network once the station has entered the network.

2.7.2 MAC Layer Data Services

There are three data service routines which are provided by the MAC layer to the logical link layer. The first routine is MAC_SEND_DATA and is used to send a data packet to the physical layer. The only parameter is the data which is to be sent. The second data service routine is MAC_RCV_DATA and is used to receive data from the physical layer. The only parameter is the data. The last service is in the form of a status variable and is named MAC_SEND_CONFIRM. This variable is used to indicate when the data has been passed to the physical layer. The data service routines are listed below:

MAC_SEND_DATA(DATA)
MAC_RCV_DATA(DATA)
MAC_SEND_CONFIRM

2.7.3 MAC Layer Network Services

There are two MAC network services. The first is IN_NET which is a boolean variable used to indicate when the station is in the network. The second service is ENTER_NET and is used to enter the network. This routine returns the channel number the network is operating on.

2.7.4 MAC Layer Implementation

This section gives some sample code for implementing the MAC layer. This code is only a guideline for implementation.

Before the code can be developed for the MAC layer the CSMA method should be understood. This method is used to help avoid collisions which can occur when two stations transmit at the same time. To prevent these

collisions a station wishing to transmit will first listen to the network to determine if another station is transmitting. If the medium is idle the station will transmit. Otherwise, the station will wait some period of time before trying to transmit again. The MAC layer will use a p-persistent CSMA method for controlling access to the medium. The p-persistent method provides the best throughput versus offered load of any of the CSMA methods. The three rules for p-persistent are:

1. If the medium is idle, transmit with probability p, and delay with probability (1-p). The time unit typically equal to the maximum propagation delay.

2. If the medium is busy, continue to listen until the channel is idle and repeat step one.

3. If the transmission is delayed one time unit repeat step one.

The value for p can be approximated by $Np < 1$, where N is the number of stations with messages to transmit. Listed below are subroutine which implement the data service routines:

```
MAC_RCV_DATA(DATA)

/* Routine to receive data
        returns the number of bytes if data is available and returns
        zero if no data calls:

                PHYS_RCV_DATA
*/

        if (! IN_NET) ERROR(NOT_IN_NET)
        return(PHYS_RCV_DATA(DATA))


MAC_SEND_DATA(DATA)

/*      Routine to send data
        no value is returned

        calls:

                PHYS_SEND_DATA
                PHYS_BUSY
                RAND    - library routine
                WAIT_SLOT_TIME  - Delay one packet time

        Uses:   IN_NET
*/
```

```
          if (! IN_NET) error(NOT_IN_NET);
          MAC_SEND_CONFIRM = FALSE;
          while(1)
                  while(PHYS_BUSY);
                  if ((RAND() *100) > 99)
                  PHYS_SEND(DATA);
                  MAC_SEND_CONFIRM = TRUE;

                  WAIT_SLOT_TIME();


ENTER_NET()

/*        Procedure used to enter the network
          returns AJ channel if successful
          returns -1 if failure

          calls:  NET_ACCESS

          Uses:   NET_ACCESS_RETRY
*/

          retry = NET_ACCESS_RETRY;       /*retry count*/
          while(retry--)
                  if (chan = NET_ACCESS())
                  IN_NET = TRUE;
                  return(chan);

          return(-1);


NET_ACCESS()

/*        Procedure to gain access to network
          Returns AJ chan if access was successful
          Returns -1 if access failure
          Access failure is defined as a time out on
          NET_SYNC.
          NET_SYNC returns the AJ channel if sync was found

          calls:  WAIT_NET_SYNC
          PHYS_AJ_SET

*/

int       chan;
          if ((chan = WAIT_NET_SYNC()) == -1) return(-1);
          PHYS_AJ_SET(chan);
          return(chan);
```

```
WAIT_NET_SYNC()

/*        procedure to wait for network sync
          returns the AJ channel if successful
          return -1 if timeout occurs

          calls:  PHYS_WAIT_SYNC
          NET_SYNC_TIMER

*/

          arm(NET_SYNC_TIMER);
          while (NET_SYNC_TIMER)
                  if(chan = PHYS_WAIT_SYNC()) return(chan);
          return(-1)
```

2.8 Physical Layer

The physical layer is responsible for the transparent transmission of bit streams across the physical interconnection of systems.

2.8.1 Physical Layer Functions

The physical layer must provide the following functions:

Encoding/Decoding. The physical layer will handle any coding which is needed to create the waveform and to provide the antijamming signal.

AJ Frequency hopping. The physical layer will provide the frequency hopping transmission and reception. The random number generator will be managed by the physical layer along the the various frequency hopping patterns.

Non AJ transmission. The physical layer will provide a non-frequency hopping mode.

Network Sync. The physical layer will transmit the signal necessary to allow other stations to obtain network sync. The physical layer is also responsible for obtaining network sync.

Packet Sync. The physical layer is also responsible for transmitting the signal such that the other stations can obtain packet sync. The physical layer must obtain packet sync from the received packet.

Interrupt Recognization. The physical layer must be able to recognize an interrupt signal from another station and report it to the medium access control layer.

2.8.2 Physical Layer Data Services

There are three data services provided by the physical layer to the medium access control layer. The first service is PHYS_BUSY and is used to indicate when the physical medium is busy. The only parameter is a boolean status flag. The second service is PHYS_SEND and is used to send a packet of data. The only parameter is the data packet to be sent. The last data service is PHYS_RCV and is used to receive data from the medium. The only parameter is the data packet that was received from the medium. The data services are listed below:

```
PHYS_BUSY(VAR STATUS : BOOLEAN)
PHYS_SEND(VAR DATA : PACKET)
PHYS_RCV(VAR DATA : PACKET)
```

2.8.3 Physical Layer Network Services

There are several physical layer network services. The first of which is PHY_AJ_SET and is used to set the AJ channel of the station. The only parameter is the AJ channel. A service to set the nonAJ channel is also provided and is named PHYS_NAJ_SET. The only parameter is the nonAJ channel. The service PHYS_WAIT_SYNC is used to indicate when the station has network sync. This service routine returns the channel number if sync was found and returns a failure code if the network sync was not found. Another service which is provided is PHYS_RESET and is used to reset the physical layer. This service has no parameters. The service PHYS_INT is used to indicate when the physical layer has detected an interrupt. The only parameter is the status. The last service is PHYS_TIME and is used to report the network time. The only parameter is the time. The network services are listed below:

```
PHYS_AJ_SET(VAR CHANNEL : INTEGER)
PHYS_NAJ_SET(VAR CHANNEL : INTEGER)
PHYS_WAIT_SYNC() : INTEGER
PHYS_RESET()
PHYS_INT(VAR STATUS : BOOLEAN)
PHYS_TIME(VAR TIME : INTEGER)
```

HF RADIO SYSTEM NETWORKING

PART 3.

Network Design Descriptions

3.1 Suggested Test Topologies

The test topologies suggested in this section have been chosen to illustrate the networking features that are part of the network concept described in this report. It is assumed that the network is logically connected in a star configuration except when a node is broadcasting an "all-call" message or a subnet is in operation. Physically, the network will be either completely or irregularly connected.

A reasonable first test topology would be a simple three-node network that has the following physical connectivity:

```
                              0
                            * *
                          *   *
                        *     *
                      *       *
                   *          *
Network ------> 0             *
Control       *   *           *
            *       *         *
          *           *       *
        *               *     *
      *                   *   *
     0* * * * * * * * * * * * 0
```

This network has complete physical connectivity and would illustrate the conditions when the nodes of the local group are located in the same general area.

This configuration can also be used to show the operation of a detached subnet. A diagram of the topology is shown below where the two bottom nodes form the detached subnet and the plus signs indicate the subnet links to network control. Remember that the subnet is using a different AJ channel.

```
                             O
                           *
                         *
                       *
                     *
                   *
Network ------> O
Control       +   +
            +       +
          +           +
        +               +
      +                   +
    O* * * * * * * * * * * * O
```

The next step would be to situate two of the nodes so that they must relay to reach network control and each other. This could be done using both directed and random routing. The diagram of this topology would be:

```
                             O
                           * *
                         *   *
                       *     *
                     *       *
                   *         *
Network ------> O            *
Control                      *
                             *
                             *
                             *
                             *
    O* * * * * * * * * * * * O
```

The next step would be to show routing that must include network control and the relay of the message to another local group. the connectivity diagram would look like this:

```
    O                        O
      *                    *
        *                *
          *            *
            *        *
              *   *
Network ------> O +++++++++++++++++++++ O <---- Network
Control           *                     *       Control
Local Group 1       *                   *       Local Group 2
                      *                 *
                        *               *
                          *             *
    O* * * * * * * * * * *  O           O<---- Destination
                                               Node
    ^
    |
    |____ Source
          Node
```

Although more nodes are shown, this test could be done with only five radio terminals.

3.2 Network Transmission Modes

There are several different transmission modes that can be identified for purposes of designing the packet header and selecting the modulation type. These modes can be identified by the table of attributes listed below:

State 0	State 1
AJ	NO AJ
MESSAGE	INSTRUMENTATION CONTROL
DATA	VOICE
BROADCAST	POINT-TO-POINT
PACKET RELAY	NO PACKET RELAY
PACKET ACKNOWLEDGE	NO PACKET ACKNOWLEDGE

The attributes are mutually exclusive between columns. For example, there is data or voice but not both in a single transmission.

A transmission mode is characterized by chosing an item from one one of the columns for each row. For example, a transmission could be made that has the following attributes:

Frequency Hopped (AJ), Message, Digital Data, Point-to-Point, with Relay and Packet Acknowledge.

The mode could also be characterized in compact notation with a mode vector describing which attribute is in use. For example, the binary mode vector 100101 would denote no AJ, message, digital data, point-to-point, with Relay but no Acknowledge. There are a large number of possible combinations but only a few are appropriate.

A graphical representation of the mode structure can also be used to illustrate the selection of the most appropriate combinations. The general scheme of all possible choices is being shown in the figure below labeled "Template of Choices". Since all of the choices are not reasonable, the next step is to modify the template of choices for AJ and non-AJ operation.

Template of Choices

```
                                                         :-- Ack
                                             :-- Relay---:
                                             :           :-- No Ack
                              :-- Point------:
                              :    to        :           :-- Ack
                              :   Point      :-- No   ---:
                              :                  Relay   :-- No Ack
         :-- Digital ---------:
         :   Voice            :                          :-- Ack
         :                    :              :-- Relay---:
         :                    :              :           :-- No Ack
         :                    :-- Broadcast--:
         :                                   :           :-- Ack
         :                                   :-- No   ---:
         :                                       Relay   :-- No Ack
         :
         :                                               :-- Ack
         :                                   :-- Relay---:
         :                                   :           :-- No Ack
         :                    :-- Point------:
         :                    :    to        :           :-- Ack
         :                    :   Point      :-- No   ---:
         :                    :                  Relay   :-- No Ack
AJ--:----:-- Digital----------:
         :   Data             :                          :-- Ack
         :                    :              :-- Relay---:
         :                    :              :           :-- No Ack
         :                    :-- Broadcast--:
         :                                   :           :-- Ack
         :                                   :-- No   ---:
         :                                       Relay   :-- No Ack
         :
         :                                               :-- Ack
         :                                   :-- Relay---:
         :                                   :           :-- No Ack
         :                    :-- Point------:
         :                    :    to        :           :-- Ack
         :                    :   Point      :-- No   ---:
         :                    :                  Relay   :-- No Ack
         :-- Instrumentation--:
             Control          :                          :-- Ack
                              :              :-- Relay---:
                              :              :           :-- No Ack
                              :-- Broadcast--:
                                             :           :-- Ack
                                             :-- No   ---:
                                                 Relay   :-- No Ack
```

The next step in the design process is to modify the template of choices to eliminate the meaningless ones. For example, broadcast with acknowledge is not meaningful so the acknowledge option is removed whenever broadcast is chosen. The following diagram shows the meaningful options for Frequency Hopping (or AJ).

Frequency Hopping

```
                                                          :-- X
                                              :-- XXX-----:
                                              :           :-- X
                               :-- Point------:
                               :    to        :           :-- X
                               :   Point      :-- No   ---:
                               :                  Relay   :-- No Ack
         :-- Digital ----------:
         :   Voice             :                          :-- X
         :                     :              :-- XXX-----:
         :                     :              :           :-- X
         :                     :-- Broadcast--:
         :                                    :           :-- X
         :                                    :-- No   ---:
         :                                        Relay   :-- No Ack
         :
         :                                                :-- Ack
         :                                    :-- Relay---:
         :                                    :           :-- No Ack
         :                     :-- Point------:
         :                     :    to        :           :-- Ack
         :                     :   Point      :-- No   ---:
         :                     :                  Relay   :-- No Ack
AJ ------:-- Digital-----------:
         :   Data              :                          :-- X
         :                     :              :-- Relay---:
         :                     :              :           :-- No Ack
         :                     :-- Broadcast--:
         :                                    :           :-- X
         :                                    :-- No   ---:
         :                                        Relay   :-- No Ack
         :
         :                                                :-- Ack
         :                                    :-- Relay---:
         :                                    :           :-- No Ack
         :                     :-- Point------:
         :                     :    to        :           :-- Ack
         :                     :   Point      :-- No   ---:
         :                     :                  Relay   :-- No Ack
         :-- Instrumentation--:
             Control           :                          :-- X
                               :              :-- Relay---:
                               :              :           :-- No Ack
                               :-- Broadcast--:
                                              :           :-- X
                                              :-- No   ---:
                                                  Relay   :-- No Ack
```

Next, we can consider the logical structure when no frequency hopping is needed.

No Frequency Hopping
(TBD)

(TBD)

3.3 Channel Concept Definitions

3.3.1 AJ Channel

The historical use of the word channel in HF radio has been to denote a particular carrier frequency and bandwidth used for communication. The terminology AJ Channel is used in frequency hopping systems to denote the pseudorandom frequency sequence used for frequency hopping. To be able to operate on a specific "channel", the radio terminal must know the hop sequence code and the time-of-week reference necessary for proper code position. The synchronization process provides the necessary information for time-of-week determination.

The hop sequence code is used by the PN code generator to determine the proper random code word sequence. The random code word data stream is used to command a frequency synthesizer that ultimately determines frequency that has been transmitted.

The hop sequence code (or key) is determined by the node address, the security keys, and the level of authority. The radio terminal code state is under software control and, with appropriate security keys, the node may be enabled for any hop sequence code.

The suite of frequencies used for an AJ channel is the same for all local groups using that channel. It is the hopping sequence (or order) in which the frequencies are used that is uniquely determined. For a reasonable number of users, the random hopping allows a few co-located local groups to use the same AJ channel designation and still maintain a low number of collisions. As the number of users becomes large, the collision rate grows to an unacceptable level.

The information processing used to determine the hopping sequence can be be represented using the following formula:

$$\begin{array}{c} \text{AJ Channel Code} \\ + \\ \text{Group Address} \\ + \\ \text{Security Keys} \end{array} = \text{Hopping sequence code}$$

A block diagram of a representative scheme for generating the code sequence that commands the frequency synthesizer is shown below:

```
                    :---------------:
                    :  AJ Channel   :<------------+
                    :  Code         :             |
                    :---------------:             |
                           |                      |
                           v                      |
                    :---------------:             |    :-----------------:
Group               :  Group        :             +----: AJ Channel      :
Address ------->:   :  Address      :             |    : Selection       :
Input               :---------------:             |    :-----------------:
                           |                      |
                           v                      |
                    :---------------:             |
Key                 :  Security     :             |
Input --------->:   :  Key(s)       :             |
                    :---------------:             |
                           |                      |
                           v                      |
                    :---------------:             |
                    :  PN Code      :             |
                    :  Generator    :             |
                    :  2**24 13-bit :             |
                    :  Words        :             |
                    :---------------:             |
                           |                      |
                           | 2**13                |
                           v                      v
                    :---------------:
                    :  Modulo       :   Channel Span and
                    :  Concentrator :   Number of Channels
                    :  (Mapper)     :<-----------
                    :---------------:
                           |
                           | 2**13
                           v
                    :---------------:
Transmission        :  LSB          :
Mode ---------->:   :  Truncator    :
(SSB, DATA etc):---------------:
                           |
                           | 2**13
                           v
                    :---------------:
                    :  Frequency    :
                    :  Synthesizer  :
                    :  Control      :
                    :---------------:
```

3.3.2 Acquisition Channel

Interleaved with the AJ Channel is the hopping sequence used for synchronization. The sync sequence is a short repeatative sequence that allows a receiver to achieve acquisition channel hop sync and then decode the time-of-week so that the AJ channel may be acquired. The interleaving algorithm is determined by the hop sequence code and the Acquisition Channel designation in current use by the local group. Interleaving is simple and does not cause a loss of data frames. The channel throughput is reduced by an amount in the range of 10-40 percent in order to accomodate acquisition within a time interval corresponding to one packet length.

When a radio terminal must join the network in a "cold start" mode, it may not be able to achieve sync due to intelligent jamming of the hopping frequencies and sequence used for acquisition. The AJ margin for stations already synchronized is not degraded.

The acquisition channel in not related to the AJ channel and must be entered separately when the node is configured. The local group must predetermine an agreeable acquisition channel. This permits a node to achieve acquisition without knowledge of the AJ channel in current use. The AJ Channel in current use is also decoded from the data blocks in the sync channel.

3.3.3 Priority Interrupt Channel

This is a hopping sequence of several frames that occurs at the end of a packet. It uses less than 5 percent of the total packet time. During the hop dwell times that correspond to the priority interrupt channel, the transmitting station listens for interrupt signals. If these are detected, the station halts message transmissions and services the interrupt. The implementation of this capability and its successful use depend upon maintaining knowledge of the absolute time delay between stations.

The priority interrupt channel, unlike the acquisition channel, is uniquely determined by the AJ channel.

3.4 Node Addressing

The address block in each packet must accomodate the following addresses:

1. Source node (the node that is the message source).
2. Destination node (the node receiving the message).
3. Routing nodes (to support a directed routing protocol).

This means that the capacity of the address block must be large enough to accomodate several address codes. A typical organization might be:

Source Address Code	Destination Address Code	Relay-1 Address Code	Relay-2 Address Code	Relay-3 Address Code	Relay-4 Address Code	" " "

This volume of address information puts a severe burden on the message thruput of the network. If relay addresses are needed it is unclear how many are practical. The ability to do rapid circuit re-establishment for directed routing may require relay address information. As a minimum, a single relay address might be very helpful in the majority of relay applications. Although it is unclear at this time how many bits might be needed for each node address, preliminary estimates indicate that 50-60 bits may be adequate.

The structure of the address code must accomodate the following:

1. A network group hierarchy.
2. An "all-call" address in the local group.
3. Network Control Cluster address sequence.

As an example of a possible address code structure, consider the following address block organization represented with hexadecimal numbers. A hex code was chosen for simplicity of illustration but actual addressing would use a much more efficient encoding scheme.

Address Code = A22E6A33B44C

=

A	22	E6	A3	3B	44C
tier 6	tier 5	tier 4	tier 3	tier 2	tier 1

Each tier represents a higher address in the network tree structure. The tier 1 address represents the address field for the nodes below the network control cluster in the local group. Tier 2 represents the network control cluster for the local group. Successively higher tiers correspond to higher levels in the network structure.

A typical local group would have an address designation of A22E6A33B000. This address would also represent the all-call address for this local group. Any node desiring to broadcast to all nodes in the local group would use this address. The network control cluster could reserve addresses A22E6A33B001-A22E6A33B00F and the rest of the nodes would be assigned addresses A22E6A33B010-A22E6A33BFFF. Normal network management and relay to higher tiers would be done through network control address A22E6A33B001, as the other members of the cluster would be shadowing that node. The node addresses for the network cluster could also designate the order of succession.

Network control for this local group would be a member of another group at the next tier. In this case it is the 3B member of the tier 3 group

designated as A3. The all-call address for this group would be A22E6A300000 and the tier 3 network control cluster could reserve addresses A22E6A301000-A22E6A30F0000. This scheme could be continued up through all the tiers.

The network control cluster needs to maintain several tables of information on addressing to be able to manage subnets and relays to higher network tiers. For example, a table used to manage subnets and the nodes in a subnet might be arranged as follows for a local network group containing 18 nodes:

Subnet Number	AJ Channel	Nodes (A22E6A33BXXX)
0	23	001, 009, 013, 016, 017, 018
1	47	005, 007
2	10	003, 006
3	52	010, 011
4	33	015, 002
5	35	012, 014
6	86	008, 004

With a suitable database organization, this table could be used to determine what AJ Channel to use to join or interrupt any subnet.

To communicate with other local groups or network control clusters at the next higher tier, the table that would allow synchronication and then access might look like this:

Tier Number	Cluster Address	Sync Channel	Tier Designation/Security Key
2	A22E6A33B001	55	"Alpha Fox"
2	A22E6A33C001	11	"Alpha Tango"
2	A22E6A33D001	39	"Alpha Bravo"
2	A22E6A33E001	83	"Alpha Delta"
2	A22E6A33F001	25	"Alpha Zulu"
2	A22E6A340001	77	"Alpha Charlie"
3	A22E6A301000	09	"Hotel Fox"
3	A22E6A401000	11	"Gulf Gulf"
3	A22E6A501000	41	"Fox Hotel"

3.5 Packet Description by Layer

The concept of a "packet" of data exists for each of the layers from the physical layer (layer-1) to the session layer (layer-5). The packet has a generic definition at each level that is very similiar for all the layers but the design or implementation structure of a packet is very different from layer to layer. The following descriptions show both generic and implementation structure as the packet is passed from layer to layer. The packet grows in information content as it passes from a higher layer to a lower layer because the of the added information needed for layer management. At the physical layer, the added information must support network access and hop synchronization.

3.5.1 Physical Layer Packet Structure

3.5.1.1 Generic Structure

The link layer packet is received by the physical layer and the data is organized into a physical layer packet. This packet is called a Physical Service Data Unit (PSDU).

Physical Layer Packet (or Physical Service Data Unit)

Packet Preamble	Physical Layer Management Information	Link Layer Packet Data

3.5.1.2 Implementation Structure

A physical layer packet is a collection of hop frames organized in a specific way. The time duration of a packet is the minimum transmission time allowed for any radio terminal. The packet also contains an integral number of hop frames.

Conceptual organization of frames into a packet.

```
     4                  230                           4           12
:----------:---------------------------------:-----------:--------:
: Packet   :     Message, Sync, Interrupt    : Packet    : Packet :
: Preamble :            Frames               : Postamble : Null   :
:----------:---------------------------------:-----------:--------:
:  32 ms               1840 ms                   32 ms      96 ms
:
:<--- Start of transmission epoch
```

The hop frames that constitute a packet serve many different functions. These are:

1. Hop frames used for the preamble.
2. Hop frames used for hop syncronization.
3. Hop frames used for the message.
4. Hop frames used for interrupt.
5. Hop frames used for the postamble.

The location of a hop frame within the hopping sequence of a packet is significant and denotes the meaning of the data contained in the frame. A hop frame will contain several chips that are organized in a particular way. For example, with a total packet length of 250 hop frames, the number of hop frames used for each function could be assigned as follows:

1. 4 frames for preamble.
2. 60 frames for sync.
3. 166 frames for message.
4. 4 frames for interrupt.
5. 4 frames for postamble.
6. 12 frames for packet null.

A reasonable packet design with an MSK bandwidth of 5 kHz and a packet length of 2 seconds would have the following times:

1. 0.2 milliseconds per chip.
2. 8.0 milliseconds per hop frame.
3. 2.0 seconds per packet.

Each hop frame would be 40 chips long. The start of each two-second packet is called the transmission epoch. The chip organization for each hop frame is shown in the following diagram.

```
                    Hop Frame Organization

     5                    32                         3
:----------:--------------------------------:-----------:
: Hop Frame:       Message Chips            : Hop Frame :
: Preamble :                                : Null      :
:----------:--------------------------------:-----------:
: 1.0 ms                 6.4 ms                0.6 ms
:
:<--- Start of hop frame epoch
```

The message efficiencies for these typical packet and frame organizations can be calculated in the following manner. The message frame efficiency for this type of design is the ratio of the frames used just for the message to the total number of hop frames per packet:

166/250 => 0.664 (66.4 percent)

The remaining 84 hop frames are used for synchronization and network management. The message chip efficiency for a hop frame is the ratio of the number of chips used just for message to the total number of chips in a hop frame:

32/40 = 0.80 (80.0 percent)

(TBD)

3.5.2 Link Layer Packet Structure

3.5.2.1 Generic Structure

The network layer packet is received by the link layer and the data is organized into a link layer packet. This packet is called a Data-Link Service Data Unit (DLSDU).

```
  Link Layer Packet (or Data-Link Service Data Unit)
:----------:-----------------:-----------------------------------:
: Packet   : Link Layer      :                                   :
: Preamble : Management      :     Network Layer Packet Data     :
:          : Information     :                                   :
:----------:-----------------:-----------------------------------:
```

3.5.2.2 Implementation Structure

(TBD)

3.5.3 Network Layer Packet Structure

3.5.3.1 Generic Structure

The transport layer packet is received by the network layer and the data is organized into a network layer packet. This packet is called a Network Service Data Unit (NSDU).

Network Layer Packet (or Network Service Data Unit)

Packet Preamble	Network Layer Management Information	Transport Layer Packet Data

3.5.3.2 Implementation Structure

(TBD)

3.5.4 Transport Layer Packet Structure

3.5.4.1 Generic Structure

The session layer packet is received by the transport layer and the data is organized into a transport layer packet. This packet is called a Transport Protocol Data Unit (TPDU).

Transport Layer Packet (or Transport Protocol Data Unit)

Packet Preamble	Transport Layer Management Information	Session Layer Packet Data

3.5.4.2 Implementation Structure

(TBD)

3.5.5 Session Layer Packet Structure

3.5.5.1 Generic Structure

The data stream from the presentation layer is received by the session layer and is organized into a session layer packet. This packet is called a Session Protocol Data Unit (SPDU).

Session Layer Packet (or Session Protocol Data Unit)

Packet Preamble	Session Layer Management Information	Presentation Layer Data

3.5.5.2 Implementation Structure

(TBD)

3.6 Description of Synchronization Technique

A synchronization sequence (or channel) is embedded in every packet transmission so that it is possible for a node to synchronize on any packet it can receive. When a radio terminal is initialized (for example, at power up) the local time reference is set arbitrarily. After this, all timing references from any network transaction are stored as an offset from this time.

Normally, the receiver is constantly scanning and synchronizing with the packets being received. To do this, the synchronization sequence is first acquired and then the locally generated hop sequence for the receiver is brought into alignment with that received from the transmitting node. This alignment will be relative to the local time reference and not to any absolute time because of the unknown propagation delay. The synchronization sequences at the source node and the destination node cannot have the same time alignment unless the propagation delay is accounted for. Propagation delay will range from a few tenths of a millisecond for short hops to tens of milliseconds for long hops. This time range corresponds to several chips for a short hop, and can be several frame lengths for long hops.

If the signal arrives at the receiver by way of one path only, the propagation delay causes no problem. Multiple propagation paths (multipath), however, can cause major problems because the receiver must select only one of the signals for synchronization and decoding. Although multipath is defined as the arrival of the same transmitted signal by two propagation paths, the reception of a transmission from a node other than the one being decoded can cause a similiar distortion. The problem is minimal when the signal arriving on one of the paths is significantly stronger than any others because the receiver can then discriminate by signal intensity. This is most often the case when line-of-sight propagation is being used or when the two nodes are an optimum skip distance apart. As the node separation or ionospheric conditions change, there will be a region where the two paths deliver signals to the receiver which are roughly the same intensity. When this happens, special multipath signal processing must be done so the receiver can distinguish between the signals.

The worst type of multipath to deal with is the condition where the two signals arrive within a time corresponding to a chip width and are of similiar magnitudes. This will result in a high error rate that may not be able to be corrected with reasonable multipath processing.

There are many approaches to the problem of synchronizing the network and providing access for nodes that are not yet synchronized but the two approaches that will now be described are good prototypes for evaluation. The first approach is to synchronize all net members initially and calculate the ionospheric delay between each pair of nodes. A method of determining the delays with the minimum number of transmissions is discussed elsewhere in this report. This requires every node to keep a table of delays that must be updated on a periodic basis (every 10-30 minutes). The delay between nodes must be inserted at the transmitter because the receiver does not know from whom it will receive a message and, hence, could not insert the delay. This procedure works for point-to-point transmissions, but fails for a broadcast mode since there is no way, in a single transmission, to include the delays needed for all the network nodes. The technique is desirable because the network overhead needed to support synchronization is small when compared to methods that allow synchronization on every packet. To initially synchronize the receivers, and to synchronize a new net node after initialization, a longer synchronizing procedure is required.

A second approach to synchronization is to interleave the synchronization sequence into every packet. This way, there is no need to measure and keep the ionospheric delay between each pair of nodes. This method works in all situations but the packet overhead to support it can be 10-40 percent. A modification of this technique might also be used for the first synchronization method mentioned above. We will now describe a technique for interleaving the synchronization information throughout the packet.

The first step for any synchronization method is to obtain frequency hop synchronization. This means that the time slots in the hopping sequence of the local receiver are aligned with those received from the transmitting node. It is assumed that both the source and destination nodes know the correct frequency hopping sequence for the AJ and Sync Channels before synchronization is attempted.

Frequency hop synchronization involves the process of slowing down one sequence with respect to the other. An alternative is to speed up one sequence, but that requires a change in bandwidth and is not considered here. In slowing down one sequence, it is most practical to slow the receiver's sequence, especially since the transmitter may be sending a message to more than one node and cannot be tailored to individual nodes. Additionally, a slow transmitter code sequence is more vulnerable to deciphering. The receiver hopping rate is slowed to the extent that several sync chips are sent for the duration of every receiver hop frequency.

For the purpose of explanation, we will look at an example design where one-fourth of the frames in a packet are devoted to synchronization. The packet in this example is 64 frames (or hops) long excluding preamble and null frames. The frames are organized into 4 blocks of 16 frames each. The synchronization sequence has four frequencies and is repeated in each block. The blocks are represented as follows:

Frame sequence numbers

1				5				9				13				
1							4		2					3		BLOCK-1

Each small division is a frame.
Numbers 1,4,2,3 are the
sync channel frequencies.

17				21				25				29				
1							4		2					3		BLOCK-2

33				37				41				45				
1							4		2					3		BLOCK-3

49				53				57				61				
1							4		2					3		BLOCK-4

Notice that the sync frames are like a template laid down in each block. It is this repetitive nature that is necessary for synchronization in one packet. The frames not containing the numbers 1,4,2,3 are devoted to message data. The sync frequencies and the time slot in which they appear can be represented by the matrix show below. A group of four time slots will contain one sync frame. The location of the sync frame within the group of four time slots is the same as the frequency index in the matrix.

Freq					
	F1	x			
	F2			x	
	F3				x
	F4		x		
		1	2	3	4

Time Slot Sequence

The synchronization sequence generated at the receiver contains only the sync frequencies. The frequency code generator in the receiver dwells on each frequency for a time corresponding to 16 frame intervals. the frequency sequence is also described by the matrix above. The repetitive sequence in the receiver can be modeled as:

Receiver Hop Sequence

16 frames of F1	16 frames of F4	16 frames of F2	16 frames of F3

This sequence is repeated until correlation is achieved and the network time and AJ channel can be decoded. This explanation does not offer real proof that the scheme will work. To really prove it requires that the transmitter and receiver code templates be constructed and shifted to show that sliding correlation can always be acheived with two repetitions of the receiver code.

The receiver records the "hits" during two repetitions and then compares them with a correlation matrix generated by determining all possible code shifts. The comparison shows not only that the sync sequence has been detected but also when the start of the next transmission epoch will occur.

The process of hop synchronization requires interpretation of the chips and consequently is placed in the link layer of the OSI model.

The next synchronization steps to occur are the chip sync and the frame sync. The purpose of the frame sync is to determine within one chip length where the frame is. Each frame contains a preamble with a unique combination of chips that occurs nowhere else in the frame. An example is a string of five ones. The physical layer is responsible for the uniqueness of the preamble. Any other sequence duplicating the preamble must be altered at the transmitter and later corrected at the receiver. The process of altering bits is called bit stuffing. Chip sync and frame sync both occur in the preamble of the frame.

(TBD)

3.7 Ionospheric Delay Determination

One possible method of operating the network is to measure the ionospheric delay between all nodes in the network and then account for the delays in future transmissions. The advantage of this method is that less synchronizing must be done in subsequent transmissions leaving more chips available for information. This saves time. The disadvantage of this method is that it will not work in the broadcast mode. The reason for this is that the transmitting node must account for the delay, and when communicating with more than one node, the ionospheric delay for two or more nodes cannot be inserted into a single transmission. The delay cannot be accounted for at the receiving node because the receiver does not know who will attempt to communicate with it.

At the start of this procedure, all nodes in the network are turned on. One of the nodes is designated as the control node. It will be assumed here that Node 1 is the control node. Each node must be able to synchronize initially without any apriori information about ionospheric delay. Procedures for doing this are discussed elsewhere in this report.

The first step is for Node 1 to transmit in the broadcast mode to all other nodes. This transmission includes a fiducial time to be used by all nodes. Network time reckoned by Node 1's clock will be called Network Pseudo Time (NPT). Each receiving node synchronizes to Node 1's transmission and sets its clock to the time transmitted. Because of propagation delay, clocks in the various receivers will be in error from Clock 1 by differing amounts.

The next step is for another node to transmit, Node 2, say. It waits for an appropriate amount of time before transmitting to assure that all nodes have received Node 1's message. Node 2 transmits NPT as it reckoned the time from Node 1's message. All other nodes synchronize to Node 2. Each of them (including Node 1) subtracts the time recorded on Node 2's message from the time the message was received at that node. For a general notation let Δt_{iRj} (i Receives j) represent a delay (not ionospheric delay) calculated from the time Node i receives Node j's message. This is obtained by subtracting the time encoded on Node j's message from the time that Node i receives the message. For the purpose of explaining this technique, assume that the time marker in the transmitted message refers to the time that transmission starts at Node j, and the noted received time is the time that the leading edge of the message is received at Node i. After Node 2 is finished, each other node transmits in turn and the process is repeated. Each node now has measurements of Δt_{iRj} calculated from each other node's transmission. We can now calculate all of the delays between each pair of nodes.

Delay from Node 1, Δt_{1j}

The calculation for the delay between Node 1 and all other nodes is simple. The delay is given by

$$\Delta t_{1j} = \frac{\Delta t_{1Rj}}{2} \qquad j \neq 1 \quad (1)$$

Delay from Other Nodes, Δt_{ij}

Delays Δt_{iRj} and Δt_{jRi} have both been measured, but they are not known at the same node. In order to share the information, and hence make the necessary calculations, each node must transmit one more time to all other nodes. Thus to determine the ionospheric delays between n nodes there are a total of 2n broadcast-type transmissions to all other nodes. Now with all nodes knowing the measured delays, each node calculates the ionospheric delay Δt_{ij} for all other nodes using the formula

$$\Delta t_{ij} = \frac{\Delta t_{iRj} + \Delta t_{jRi}}{2} \qquad i \neq j \quad \text{and} \quad i,j \neq \quad (2)$$

If all ionospheric delays are to be determined, the advantage of this method is that fewer transmissions must be made. To determine the delays by point-to-point communications would require n(n-1) transmissions. This

value is obtained by multiplying the number of delays to be determined [1/2(n)(n-1)] times 2 because each pair of nodes must transmit time to each other so that each node can calculate the delay. In summary, for large n, the number of transmissions for a point-to-point method goes as n^2 whereas the method explained here goes as n. For more details and a specific example about this method, see the example.

EXAMPLE

In this example we discuss an a particular case of ionospheric delay determination. Refer to Figure 3.1 during the following discussion. Suppose there are five nodes in the network and Node 1 is the controlling node. The numbers along the left margin refer to node numbers. The horizontal axis is time. The time intervals were arbitrarily chosen and are not scaled. The numbers along the bottom, 1T, 2T, etc. are the times that each node transmits. At start-up time all radios are on, and Node 1 transmits time t_o as reckoned by its clock. See the upper left corner of Figure 1. This message is received by all other nodes after various time delays (Δt_{12}, etc. along the left hand edge) which are the ionospheric delays. All nodes now reference time to the t_o they received in the transmission. After a delay Δt_a Node 2 transmitts the time as indicated on its clock. (See line 2). The time intervals between the receipt of Node 1's transmission and the initiation of Node 2's transmission for Nodes 3, 4, and 5 are given on lines 3, 4, and 5, respectively. The delay between Node 2's transmission and the receipt of this by the other nodes is shown to the right of the vertical line labeled 2T. The notation 1R2, 3R2, etc. to the right of the delay indicates when Node 1 receives Node 2, etc. Nodes 1, 3, 4, and 5 then measure Δt_{1R2}, Δt_{3R2}, Δt_{4R2}, and Δt_{5R2}, respectively.

To get a typical expression for Δt_{iRj}, consider the case of Node 4 receiving Node 2's transmission. The time transmitted by Node 2 which represents the leading edge of the transmission is $t_o + \Delta t_a$. From Figure 1 we see that the time that Node 4 receives the transmission is

$$t_{4R2} = t_o + \Delta t_{12} + \Delta t_a - \Delta t_{14} + \Delta t_{24}$$

Subtracting from this the time sent encoded by Node 2 we get a measured delay of

$$\Delta t_{4R2} = \Delta t_{12} - \Delta t_{14} + \Delta t_{24} \quad (3)$$

We next turn to the transmission of Node 4. The time encoded on this message is $t_o + (\Delta t_{12} + \Delta t_a - \Delta t_{14}) + \Delta t_{24} + (\Delta t_{23} + \Delta t_b - \Delta t_{24}) + \Delta t_{34} + \Delta t_c$. The time Node 2 receives the transmission is

$$t_{2R4} = t_o + \Delta t_a + \Delta t_{23} + \Delta t_b + \Delta t_{32} + (\Delta t_{34} + \Delta t_c - \Delta t_{32}) + \Delta t_{42}$$

Subtracting from this the time encoded on the message, we get a measured delay of

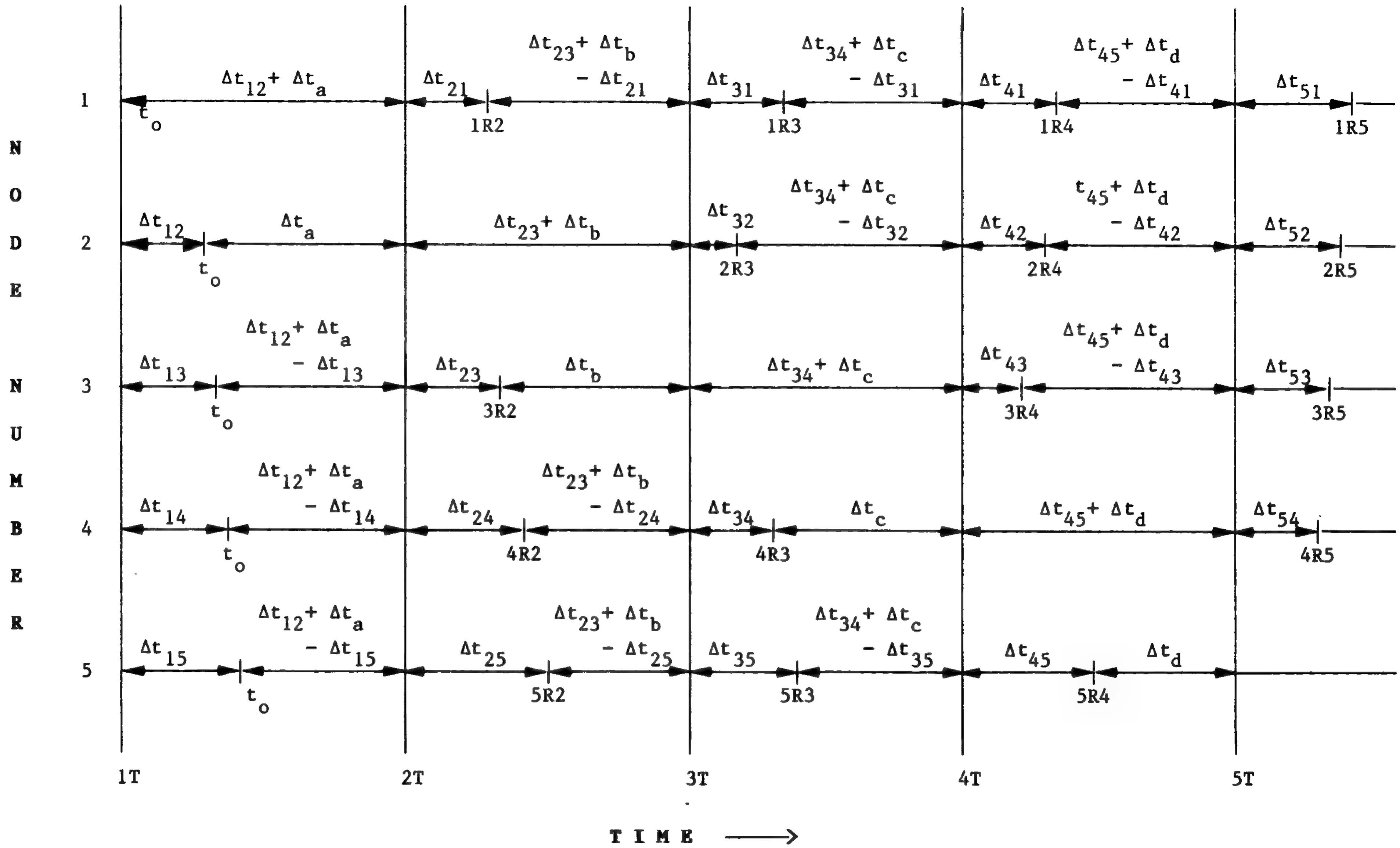


Figure 3-1. Timing diagram for transmissions and receptions from five nodes.

$$\Delta t_{2R4} = \Delta t_{42} - (\Delta t_{12} - \Delta t_{14}) \tag{4}$$

Now it is necessary to combine Δt_{2R4} with Δt_{4R2}. To get this information to a common point, another round of transmissions is required. When all nodes have finished the initial transmissions of their times, each node in turn transmits its measured Δt_{ij}. Then at each node the ionospheric delay can be calculated. In our example we calculate the delay between nodes 2 and 4. Each node adds (3) and (4) to get the desired result,

$$\Delta t_{42} = \Delta t_{24} = \frac{\Delta t_{4R2} + \Delta t_{2R4}}{2}$$

In general, we find that the delay between nodes i and j can be found from

$$\Delta t_{ij} = \Delta t_{ji} = \frac{\Delta t_{iRj} + \Delta t_{jRi}}{2}$$

For n nodes there must be a total of 2n transmissions of the broadcast type in order for all nodes to be able to calculate the delays between every pair of nodes. For large n this can be a considerable reduction in the number of transmissions when compared to the n(n-1) transmissions required for measurements made in a point-to-point type mode.

3.8 Network Transaction Descriptions

The following descriptions are given to illustrate the fundamental operations involved in a typical network message-passing transaction. The radio network will be contrasted with the phone network where practical to do so. The transaction will be described both at the logical level and physical level. The example will be two computers communicating by smart modem over the phone system.

3.8.1 Logical Network Transactions

3.8.1.1 Phone Network

Source	Network	Destination
-Determine phone number		
-Place the call	-Establish class of service and circuit	-Answer the call and say hello
-Acknowledge hello		
-Transfer message		-Transfer message
-Say goodby		-Say goodby
-Hang up	-Terminates the circuit	-Hang up

3.8.1.2 Radio Network

(TBD)

3.8.2 Physical Network Transactions

3.8.2.1 Phone network

The following description is provided so the actions taken in the radio network can be contrasted with those in the phone network. Three columns are used to group actions by the source, network, and destination. The description of the action and the reference number appear directly under the column shown in the heading.

Descriptions of Corresponding Actions

(U)=User
(P)=Phone system
(RT)=Radio terminal

(C)=Computer
(RN)=Radio network
(M)=Modem

#=additional comments

SOURCE	NETWORK	DESTINATION
:	:	:
:	:	:

1. (U) Determine phone number. ---
#The user in either the phone system or the radio system must
#acquire the number of the node to be called. This may be
#available either as a locally stored list or available as a
#directory assistance. The concept of directory assistance for
#the radio system needs further exploration. It is likely that
#the radio system will use logical names for the nodes - at
#least at the group level. The use of abbreviated names for
#actual node addresses will greatly simplify address entry.

2. (U,C) Enter the number into the computer and ---
request that a circuit be established.
#This could be analogous to dialing the number or requesting
#operator assistance. When a circuit needs to be established
#between two local groups, the assistance will be provided by
#the network control cluster of the originating node.

5. (C,M) Establish communication with the ---
modem. Set data rate and pass phone
number.
#The modem function is the same for both phone and radio.

6. (C,M) Command modem to establish circuit. ---
#

7. (M) Modem goes off-hook. ---

--- 8. (P) Local phone exchange senses off-hook condition and provides dial tone.

9. (M) Modem detects dial tone and dials the number. ---

--- 10. (P) Local phone exchange looks at the service requested (local, long distance, time, directory assistance, etc.) and the user's identity and then validates the class of service and takes the prescribed action.

--- 11a. (P) Phone network determines availability of a suitable call routing and establishes the circuit to the local exchange of the destination node. During this process, call progress signals are sent to the destination node.

11b. (U) The user monitors the call progress signals. ---

12. (P) The local exchange at the destination node determines the on-hook/off-hook status of the destination node. If on-hook, both nodes are sent a ringing signal. If off-hook, a busy signal is sent to the source node.

13a. (C) The ringing signal is monitored. if not answered, the source computer times out and notifies the user that there was no answer. ---

--- 13b. (M) The answer modem goes off-hook and sends the proper carrier tone.

--- 13c. (P) The network is notified that an off-hook has occured and keeps the circuit established until an on-hook occures at either node.

14. (M) The modem receives the tone and sends a carrier detect flag to the computer. It also sends a different carrier tone back. ---

15. (M) The modem receives the response tone and sends a carrier detect flag to the computer.

16. (C) The computer sends the protocol answer message and notifies the user a call has been received.

17. (C) The computer receives the protocol message, replies to it, and notifies the user a call has been received.

18a. (U) Message is exchanged.

18b. (U) Message is exchanged.

19a. (U) Say goodby.

19b. (U) Say goodby.

20. (U,C,M) Go on hook.

21. (P) Network senses on hook and terminates circuit.

22. (M) Modem senses loss of carrier, goes on-hook, and sends on-hook flag to computer.

23. (C) Computer notifies the user that caller has hung up.

3.8.2.2 Radio Network

Descriptions of Corresponding Actions

(U)=User
(P)=Phone system
(RT)=Radio terminal
(NC)=Network control
(C)=Computer
(RN)=Radio network
(M)=Modem

#=additional comments

SOURCE	NETWORK	DESTINATION
:	:	:
:	:	:

1. (U) Determine destination node number. ---
#
#The user of the radio terminal must
#acquire the number of the node to be called. This may be
#available either as a locally stored list or available as a

#directory assistance. The concept of directory assistance for
#the radio system needs further exploration. It is likely that
#the radio system will use logical names for the nodes - at
#least at the group level. The use of abbreviated names for
#actual node addresses will greatly simplify address entry.

2. (U,C) Enter the node number (or equivalent logical name) into the computer and request that a circuit be established. The class of circuit requested must also be entered. ---

#
#At this time, the source node must specify the Network
#Transmission Mode (i.g. frequency hopping, message, digital
#data, point-to-point, with relay and packet acknowledge),
#subnet establishment, etc.

3. (RT) Establish communication with the Network Control Cluster. ---

#
#The radio terminal automatically trys to access the local
#group and send a circuit request to the Network Control
#Cluster.

3a. (RT) Listen for network traffic and call the network control cluster using CSMA protocol. ---

#

3b. (RT) If no response is received from the network control cluster, send out a broadcast message requesting relay from any node having connectivity with the network control. ---

#

3c. (RT) If still no response, then send the message using random routing.

#

--- 4a. (NC) Network control receives the message directly from the source node and relays it, or establishes the requested relay circuit (directed routing), or sets up a requested subnet.

#

--- 4b. (NC) Network control receives the message from the source node using an intermediate relay and then relays it, or establishes the requested relay circuit (directed routing), or sets up a requested subnet.

#

--- 4c. (NC) Network control receives the message via random routing and then relays it, or establishes the requested relay

circuit (directed routing), or sets up
a requested subnet.

#

5. (U,RT) The user can monitor the process of circuit establishment by requesting this service from the network control cluster. ---

#

#This is analogous to the "call progress" signals used by the
#phone company to notifiy the user of the progress in
#establishing the circuit. If the user does not request this,
#the radio terminal still monitors this progress so it can
#report a completion or a fault.

--- 6. (NC) The action of the network control cluster of the source none is repeated in a similiar fashion at other network tiers (if any) until the network control cluster of the destination node is reached.

#

#This process is analogous to the routing that is done in the
#phone system where the local exchange passes the circuit request
#up through the various office levels until the local exchange
#of the destination phone is reached.

--- 7. (NC) The network control cluster of the destination node establishes the circuit from it to the destination node.

#

8a. (RT) The source node monitors progress until the circuit is established or times out. ---

#

--- 8b. (RT) The destination node answers.

#

9. (RT) The radio terminal notifies the user that a call or message has been received. It sends the proper protocol message to the source node.

#

10. (RT) The source node receives the protocol message, automatically replies, and notifies the user if needed.

#

11a. (RT,U) Message is exchanged.
#

11b. (RT,U) Message is exchanged.

#

12a. (RT,U) Say goodby.

12b. (RT,U) Say goodby.
#

13a. (RT) Notify network control of desire to terminate circuit.
#

13b. (RT) Notify network control of desire to terminate circuit.

#

14. (NC) The network controls that were part of the circuit receive the termination notice and act on it.

#

(TBD)

HF RADIO SYSTEM NETWORKING

PART 4.

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HF RADIO SYSTEM NETWORKING

PART 5.

Acronym and Term Definitions

ACK	Acknowledge
ADCCP	Advanced Data Communication Control Procedures
AFSK	Audio Frequency-Shift Keying
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Exchange
BSC	Binary Sequence Communication
CCITT	International Consultative Committee on Telegraphy and Telephony
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
DARPA	Defense Advanced Research Projects Agency
DTE	Data Terminal Equipment
EDAC	Error Detection and Correction
FACS	Frequency Agile Communication System
FCS	Frame Check Sequence
FDMA	Frequency-Division Multiple Access
FSK	Frequency-Shift Keying
HDLC	High-Level Data Link Control (OSI layer 2)
IMP	Interface Message Processor
ISO	International Organization for Standardization
LAN	Local Area Network
LBT	Listen Before Talk
LLC	Logical Link Control
LPI	Low Probability of Intercept
LQA	Link Quality Analysis
MAC	Medium Access Control
MSK	Minimum-Shift Keying
NAK	Negative Acknowledge
NPT	Network Pseudo Time
NSDU	Network Service Data Unit
NVI	Near Vertical Incidence
OSI	Open Systems Interconnection
PAD	Packet Assembler/Disassembler
PCM	Pulse Code Modulation
PLSDU	Data-Link Service Unit
PSDU	Physical Service Data Unit
SDLC	Synchronous Data Link Control
SPDU	Session Protocol Data Unit
TBD	To Be Determined
TCP	Tramsmission Control Protocol
TDM	Time-Division Multiplexing
TDMA	Time-Division Multiple Access
TMS	Time Multiplex Switching
TPDU	Transport Protocol Data Unit

BSC Control Characters

ETB	End of transmission block
ETX	End of text
RVI	Reverse interrupt: a positive acknowledgment that requests that the transmitting station terminate the current transmission because the receiving station has a high-priority message to send
SOH	Start of heading
STX	Start of text
SYN	Synchronous idle: establishes and maintains synchronization

DEFINITIONS OF TERMS

AJ Channel -

The terminology used in frequency hopping systems to denote the suite of frequencies and the pseudorandom frequency command sequence used for hopping. It is analogous to the designation of a single frequency for unhopped systems. To be able to operate on a specific AJ channel, the radio terminal must know the hop sequence code, the network time reference, and the suite of hopping frequencies.

Carrier Sense Multiple Access -

This is a technique for permitting node access to the network in a controlled fashion. It is necessary for a broadcast network. With a CSMA protocol, a node wishing to transmit listens to the medium. If it is idle, the node transmits. If it is busy, the node executes a random wait and try algorithm until success. (Ref: Stallings, P.297).

Chip -

The basic signalling unit in a binary signalling waveform. For two-tone FSK it is the time interval spent on one tone.

Circuit -

The actual node-to-node path traversed by the message including any relays.

Circuit Establishment -

The process of determining the relay links that will be used for directed routing.

Circuit Re-establishment -

The process of securing an alternate circuit when the one in current use loses a link to one of the relay nodes.

Connectivity -

A measure of the ability of two nodes on the network to communicate directly without relay. When two nodes have connectivity, it means that the communications medium will support direct communications. In the more general sense, there can exist several grades or levels of connectivity. For example, in a frequency hopping system, connectivity can be graded according to the number of hop frequencies that will support communications and the error rate for each frequency.

Connectivity Matrix -

The connectivity of all nodes in a local group can be described using a matrix. Each element of the matrix is a parameter vector that contains the characteristic parameters of the connectivity between two nodes. Diagonal elements represent the operational health of a network node. For example if node 3 is unoperational, the element (3,3) can contain a flag for this information. The matrix does not have to be symetrical because, connectivity has a direction sense. For example, Node 5 may be able to hear Node 3 but Node 3 may not be able to near Node 5 due to local noise or jamming that is not present at Node 3.

Connectivity Matrix Element Parameters -

Each element is a vector of parameters that characterize the quality of the communications medium between two nodes and the health status of each node. At the present time (Feb. 1986) these are not specified. Specification must wait until extensive networking tests with frequency hopping radio networks can be conducted.

Data-Link Service Data Unit -

The ISO/OSI model reference designation for the packet assembled at the link layer.

Directed Routing -

Directed routing is a technique similar to that used in telephones except the connectivity may be different. In this scheme, the routing circuit would be established prior to actual message handling. This type of routing would require ACK/NAK capability to get the circuit established.

Dynamic Frequency Allocation -

The process of adaptively choosing new suites of hopping frequencies with the help of link quality analysis.

Flooding-

An alternate terminology for random routing. See: Random Routing.

Hop Dwell Time -

The length of time a frequency hopping transmitter remains on a single frequency.

Interface Message Processor -

These are the network message switching elements used to interface host nodes to the network. In the HF Radio Network, this function is performed by the network control cluster.

Interleaving Length -

When the data in interleaved in time to avoid burst noise and multipath fading errors, the time separation between chips that contain equivalent information is the interleaving length.

Interrupt Channel -

A hopping sequence added near the end of the packet to permit real time interrupt of the transmitting node. It is similiar to the AJ Channel.

Link -

The radio connection or communications medium between two nodes.

Link Quality Analysis -

The ongoing process of determining the time-varying SNR and error rate for every hopping frequency in the link.

Local Group -

This is a group of nodes and their network control cluster that form the basic network unit. All of the group nodes are under network control. The local group may be star connected, completely connected, or irregularly connected depending on the selected network protocol and the communication medium. The local group is analogous to the lowest level in a military command structure or a level-5 office in the phone system.

Minimum Shift Keying -

A phase coherent form of frequency shift keying that produces a minimum bandwidth binary signaling waveform.

Network Channel -

The radio channel used by the local group for intragroup communication. It may be an AJ Channel or a single frequency and is being used as a generic term to denote the channel concept whether hopped or unhopped.

Network Control Cluster -

A group of radio terminals designated for network control functions. These terminals share message relay duties and shadow each others activity so the loss of a terminal will not seriously degrade the network performance.

Network Service Data Unit -

The ISO/OSI model reference designation for the packet assembled at the network layer.

Network Time -

The time reference used for the AJ pseudorandom hopping sequence. This time is needed when a node is trying to acheive intitial synchronization because the hopping sequence is referenced to a time-of-week. Without the time-of-week, the node would not be able to determine the AJ hopping sequence and its time reference relative to the transmitting node's local clock. The network time is also used to determine the absolute value of propagation delay between two nodes.

Node -

A junction in the network that can act as a host or a packet switch. For radio systems, a node is capable of sending, receiving, or relaying messages. See also: Radio Terminal. (Ref: Tanenbaum, P.7)

Packet Switch -

Nodes which are used to relay traffic between nodes which lack good connectivity. See (Ref: Tanenbaum, P. 7) for a discussion of other terminology such as Interface Message Processor, Communication Computer, Node, and Data Switching Exchange.

Physical Service Data Unit -

The ISO/OSI model reference designation for the packet assembled at the physical layer.

Priority Interrupt Channel -

See: Interrupt Channel.

Random Routing -

In random routing, the originating node sends packets to several nodes in the network in a broadcast mode. These packets are relayed until they reach the proper destination node. Each packet may arrive by a different circuit and at a different time. Each packet has a source node address, a destination address, and a packet number, and the total number of packets in the message. The destination node can reassemble the message from the

received packets and request retransmission of any garbled or missing packets. This technique requires each node to keep a log of messages relayed so that the same packets do not circulate forever.

Radio Terminal -

The complete complement of equipment needed to serve as a node in the network. This will include such equipment as antennas, antenna couplers, receivers, transmitters, modems, security equipment, computers, computer terminals, and any needed support equipment. For the purposes of networking discussions, the term "node" will usually be used.

Routing -

The concept used to establish a connection or circuit between the source node and the destination node(s).

Session Protocol Data Unit -

The ISO/OSI model reference designation for the packet assembled at the session layer.

Sync Channel -

Similiar to the AJ Channel in format and design. The hop frequencies and time slots for the Sync Channel are interleaved with those of the AJ Channel.

Time-of-Week -

See: Network Time.

Transport Protocol Data Unit -

The ISO/OSI model reference designation for the packet assembled at the transport layer.

Virtual Circuit -

The circuit as perceived by the source and destination nodes. The goal of good radio network is to provide a virtual circuit having a reliability approaching that of a computer LAN.

HF RADIO SYSTEM NETWORKING

PART 6.

Quick Topic Reference

Part 1

1.0 System Overview

1.1 Introduction
- Working definition of HF radio network
- Some nodes have executive functions
  - Net can establish predetermined circuits (directed routing)

1.2 General description
- Comparison with telephone system
  - HF network attributes not in phone system
    - Broadcast network
    - Supports random and directed routing
    - Variable degress of connectivity
    - Temporary detached networks
  - Additional complications in HF network
    - Frequency hopping
    - Narrow bandwidths
    - Data interleaving

1.3 Network Operation
- Implementing network and protocols
  - Net control cluster has security keys and sync channel for other groups
- Implementing priority interrupt
  - Local group needs prop. delay
    - Put into connectivity matrix
  - If no interrupt available
- Interrupt
  - This paragrph overlaps with interrupt paragraph in ACCESS
- Universal net time
  - No known way to get this now
  - Use time-of-week and table of prop. delays
    - Delays not required for net operation
- Packet length
  - 1/2 to 4 seconds
  - ACK/NAK protocol
- Link and physical layer functions
  - Performed by modem
  - ISO description should not be constraint - said before

Multiple data rates
- Selected by signalling mode
- Max rate may be restricted
- Each stage of information handling needs data buffering for either sync of ASYNC operation
- Implementation interface appears synchronous

Synchronous transmission
- May support this for two nodes with high connectivity
- Probably will not do this

DTE synchronism
- Handled at each radio; transparent to network
- Totally restructured at destination
- Baud rate, word length, etc. handled in application and presentation layers

How communications accomplished
- Not specified now
- Comments
  - Local nodes have same security keys, same sync
    - This allows sync and time-of-week and AJ channel
  - Acquire AJ channel and access net by CSMA
  - No access to another group
    - Must go through Net Control Cluster

CSK
- Embed in some sync frames
- Modem sends CSK code
  - EDAC should use this; we don't know how yet

Packet overhead
- Comes from hop sync, packet preamble, packet addressing, and control
- Large
- Efficiency ~ 60%

AJ channel monitoring
- Radio decodes all messages
- Higher layers respond to their address only
- Gathers LQA and delay information continually
- Radio hop syncs anew for each new node
  - Can avoid only by having delay information

Suite of frequencies derived from security keys

Nature of messages
- Needs more study

Constraints on FACS
- R/T transition time ~ 20 ms
- LPI - variable power levels

Dynamic frequency allocation
- Not being proposed
- High overhead
- Could be a special mode in detached subnet
- Nodes need current connectivity matrix

AJ channel designations
- Suite of hop frequencies - 256 suites
- Pseudorandom frequency

1.4 Topology

- Fully connected
- Star-connected
  - Hierarchy of stars
  - Lowest star is local group
  - Not always in star because can have direct connection
  - Any node can do an "all-call"
  - No need for net control to relay
  - Coordinated by net control
- Local network group
  - Connected similar to end office and local loops of phone net but don't need relay through net control
  - Net control may require permission
  - Net control approves detached subnet
- Alternate scheme for local net
  - Assign each node to a different AJ channel
  - Access only through net control
  - Restrictive - don't need so much privacy
  - Could use subnet for privacy
  - Majority of messages will be "all-call"
- Networking demonstration
  - Five nodes
  - Control cluster diagram
  - Connectivity matrix
- Example of detachment
  - Sketch
  - Connectivity matrix
- Succession order of control cluster
  - Pre-established order, N1a, N1b, N1c, etc.
  - Inop node - new one put on bottom
  - All these nodes have high connectivity
  - Constant number of control nodes
- Low initial connectivity
  - No change during message transmission
  - If circuit broken, must re-establish
  - Destination node identifies erroneous packets
  - If connectivity volatile, use random routing
  - For high volume point-to-point
    - Establish relays with good connectivity
    - Direct routing
- No connectivity with control
  - Station node finds a connected station node to be relay
  - Select relay node from connectivity matrix
  - Request help in "all-call" mode
  - Node addressing structured similar to military commands
- Need communication outside local group
  - Use directed routing
  - Network control cluster have security keys for synch with other networks
- Higher level star
  - Analogous to Level 1, 2, 3, 4, etc. of phone system
    - Connectivity difference
    - Can connect net control in one group to station in another
  - Need to regulate this

1.5 Net Transaction Description
- Introduction
- Logical network transactions (phone network)
  - Several steps outlined such as
    - Look up phone number
    - Place call
    - Establish circuit
    - etc.
- Physical network transactions

1.6 Access
- Three aspects
  - Initial waveform synchronization
  - Routine access
  - Interrupt access
- Routine access
  - Regulated using CSMA
  - Listen-with-random-try-and-timeout
  - May have collision problems
  - Needs more thought
- Initial access
  - Hop, chip, frame, packet sync
  - Node with security keys etc. can sync and decode time (time-of-week)
  - Can do initial sync with one packet
- Interrupt long message
- Souce node listens near end of each packet
- Interrupter must know ionospheric delay

1.7 Routing
- Intro-Random and directed
- Flexibility
  - Various waveforms
  - Network protocols
  - Compatibility with existing equipment
- Directed routing
  - Definition
  - ACK/NAK for relaying
  - Establish circuits out of local group
  - More efficient than random routing but less robust
  - Packet contents
    - Addressing
    - Relay nodes
- Random routing
  - Definition
  - Flooding
  - Packet contents
    - Source address
    - Destination address
    - Packet number
    - Relay identifier
    - Number of packets
  - Destination node reassembles

- Problems
  - Stop rebroadcast cycle
  - Random arrival time for packets
  - Message log at each node
  - Keeping track of retransmitted packets at receiver
  - Requesting retransmission of garbled packets

1.8 ISO/OSI Model Overview

- Introduction
  - List of 9 layers plus management
  - Medium and User are not part of OSI
  - Apartment house diagram
    - Source, relay and destination
    - Communications medium
  - General comments
    - Information flows vertically
    - Four lower layers used in relaying but relay node has all layers
  - Diagram with management layer
    - Talks to all 7 layers
    - No talking to User or Medium
- Communication medium
  - Major influence on network design
    - Affects connectivity
    - Affects access
    - Affects bandwidth
    - Affects reliability
  - Discussion of wires, coax, satellites
  - Phone system
- Layer description summaries
  - Physical layer
    - Physical and link layers are functionally separate in model, but have physical overlap
    - Transmission and reception of signals
      - Definition of chips
      - Bits → chips
      - Issues addressed
        - Waveform
        - Rate
        - Frequency
        - Etc.
    - Physical and functional elements
      - Carrier sense
      - Frequency-hopping
      - R/T hardware and software
      - Antenna coupler
      - Antenna
- Data link layer
  - Provides error-free transmission and reception
  - Process bit stream from physical layer
    - Removes transmission errors
  - Organizes packets
    - Packet assembly/disassembly
    - Error encoding/decoding

Multipath and dispersion correction
Data interleaving
Data buffering
Processes bit stream from network layer - transmission
Error detection and correction
Data interleaving
Encoding
Packet preamble
Packet header
Frame check sequence
Process bit stream from physical layer - receiving
Error detection and correction
Data de-interleaving
Multipath and dispersion correction
Packet decoding
Frame check sequence decoding
Manage garbled or missing packets
ACK/NAC control
Buffer transmitted packets
Decode node address
Decode packet number
Decode message number
Received packets
Buffer
Order correctly
Initiate transmission of any ACK packets
Standardized compatibility
e.g. Level protocol X.25 or AX.25
Packet assembler/disassembler
Hardware unit
Implements standard protocol
Interfaces a modem at physical layer
Interfaces a computer at network layer
Not officially part of OSI model
Network layer
Orders bit stream received by transport layer
Provides authorized class of service
Determines the type of routing
Examples, X.25 or X.75
Transport layer
Session layer
Presentation layer
Application layer
User

1.9 Signal and Physical-Layer Packet Structure
Tradeoffs
Ease of hop sync
Network thruput
Packet ID overhead
Interleaving length for error detection
Priority interrupt
Packet structure
Many hop frames

- Hop frame contains many chips
- Contents
    - Message
    - Control
    - Sync bits

Packet length
- Depends on hop frame and chip lengths
- Chip width determines bandwidth
- Frame length determines chips/hop dwell
- Packet length determines
    - Hop frames/packet
    - Minimum transmission interval
    - Examples of tradeoffs
- Proposed packet length
    - 1/2 - 4 seconds

Variety of signalling waveforms
- Can communicate with implemented radio systems
- Variety of data rates
- Modulation modes
    - SSB, 3 kHz
    - AFSK, 3 kHz
    - MSK unsecure data, 3 kHz
    - MSK unsecure data, 6 kHz
    - MSK unsecure data, 12 kHz
    - MSK secure data, 3 kHz
    - MSK secure data, 6 kHz
    - MSK secure data, 12 kHz
    - Digital unsecure voice (MSK or FSK)
    - Digital secure voice (MSK or FSK)

HF frequency channels
- 3 kHz width
- Channel separation = 3 kHz
    - Orthogonality needed
    - Separation of 100 Hz not needed

Constrained modulation modes
- Modes may be regulated in peacetime
- Channel spacings for 6 and 12 kHz are multiples of spacings for 3 kHz

Frequency accuracy
- 0.5 to 1.0 PPM
- Current technology can meet this
- 1.5-30 Hz in range 2-30 MHz
- Accuracy needed for frequency and phase tracking

Hop dwell time
- 5-20 ms
- Hopping rates 50-200 hops/sec
- Faster rates push RF sections

Wider RF bandwidths problems
- Dispersion gets worse
- Multipath fading gets worse
- Decoding errors
- Fewer chips/hop increase overhead

Part 2

2.0 ISO/OSI Model Design Description

2.1 Layer Overview

2.2 User Layer

2.3 Application Layer

2.4 Session Layer

2.5 Transport Layer

2.6 Logical Link Control Layer

2.7 Medium Access Control Layer

2.8 Physical Layer

Part 3

3.0 Network Design Descriptions

3.1 Suggested Test Topologies
- Three-node network plus control
  - Complete physical connectivity
  - Relaying
- Four-node network plus control

3.2 Network Transmission Nodes
- Several modes
- Example
- Template of choices
- Frequency hopping diagram

3.3 Channel Concept Definitions
- AJ channel
  - History
    - Frequency hopping
    - Need hop sequence code and time-of-week
  - PN generator
    - Need hop sequence code
    - Code controls frequency synthesizer
  - Hop sequence code
    - Determined by
      - Node address
      - Security keys
      - Level of authority
    - Radio terminal code controlled by software

- Suite of frequencies
  - Same for local groups using same channel
  - Uniqueness is in hopping sequence
  - Collisions
    - Small for few users
- Acquisition channel
  - Synchronization
    - AJ channel and hopping sequence interleaved
    - Sync sequence short and repetitive
      - Can acquire channel hop sync and time-of-week
    - Interleaving determined by hop sequence code and acquisition channel designation
    - Interleaving needs no extra frames
- Priority interrupt channel
  - Hopping sequence interleaved with AJ and acquisition channels
  - Uses < 5% of packet time
  - Source listens for interrupts; if detected, stops transmitting
  - Interrupt channel determined by AJ channel

3.4 Node Addressing

- Content
  - Source node
  - Destination node
  - Routine nodes
  - Address block
    - Source
    - Definition
    - Multiple relay addresses
  - Structure of address code
    - Group hierarchy
    - All-call address
    - Control cluster address sequence
- Example
  - 6 tiers
  - Hex labels
  - Each tier is a level in hierarchy
- Reserved addresses
- Addresses for first level control group
  - All-call address
- Volume of information
  - Burdens thruput

3.5 Packet Description by Layer

3.6 Description of Synchronization Technique

3.7 Ionospheric Delay Determination

3.8 Network Transaction Descriptions

END OF REPORT

HF RADIO SYSTEM NETWORKING